The Dissertation Committee for Julio Cesar Postigo Mac Dowall Certifies that this is the approved version of the following dissertation:

Responses of Plants, Pastoralists, and Governments to Social Environmental Changes in the Peruvian Southern Andes

Committee:

Kenneth R. Young, Supervisor

Kelley A. Crews

William E. Doolittle

Gregory W. Knapp

Camille Parmesan

Responses of Plants, Pastoralists, and Governments to Social Environmental Changes in the Peruvian Southern Andes

by

Julio Cesar Postigo Mac Dowall B.A.; M.A.

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Dedication

To my mother Elizabeth and my wife Anna

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Dissertations are the product of a collective endeavor. The subjects consent to be part of social research; professors shape the minds of their students; social networks support the academic productive process; the foundations that fund projects; all of which shapes the author's process of collecting and assembling pieces of the research puzzle into a unique product, which at the same time, reflects the collective. My committee has provided substantial support during this productive journey. Bill Doolittle's practical sense of research (and life) and critical views of flashy "new" approaches helped me understand academic legacies and focus on theoretical continuities more than radical departures. Specifically, I owe Bill for the references to Julian Steward's work on irrigation. Greg Knapp's academic transition from archaeology in the Peruvian coast to cultural and political ecology of flower production in the Ecuadorian highlands has been a constant reminder of richness of transdisciplinary scientific approaches. Kelley Crews's encouragement to challenge assumptions and normative concepts has stimulated the dialogue between data and concepts of this dissertation. Camille Parmesan has been a source of critical support, encouragement (particularly with my work with plants at high altitudes), and provides an impressive example of professionalism while navigating the murky waters of the science-policy interface.

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I produced excellent research and as long as my trips related to and improved my research.

Ken patiently read (and suffered through my sometimes rough English and Spanish-inspired writing style) several drafts of each chapter, provided critical feedback, and was sometimes more excited about this dissertation than its own author (me). Over the years, Ken has exemplified the difficult to find combination of an excellent and humble professional and a generous and trust worthy human being. Thank you both for being who you are and always being there for me.

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Responses of Plants, Pastoralists, and Governments to Social Environmental Changes in the Peruvian Southern Andes

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Julio Cesar Postigo Mac Dowall, Ph.D.

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Supervisor: Kenneth R. Young

Abstract: Anthropogenic global changes are altering properties and functions of social and ecological systems at multiple spatial and temporal scales. In addition to climate change, the Peruvian Southern Andes has also experienced dramatic political and social change. This dissertation addresses the responses of plants, humans, communities and sub-national governments to the impacts of these changes. Methods from both the social and natural sciences were used at three levels: 1) on the forelands of the Quelccaya ice cap a chronosequence approach was used and 113 quadrats ($1m^2$) sampled the vegetation covering an altitudinal range from 5113 to 4830 m.a.s.l.; 2) with the households of herders in the Quelcaya community surveys, interviews, participant observation, and archival research were employed; and 3) with the three Regional Governments (Arequipa, Cusco, and Puno) interviews with officials and stakeholders were conducted. The results show an upward displacement of the elevational limit of plants and a trend towards homogenization of vegetation. Warming climate, a shortened rainy season, and longer dry and cold spells are the most relevant impacts of climate change in the study area. Responses to these changes occur within households, supra-household units and communities, through dynamic institutions, traditional knowledge, and flexible polycentric social organization. These responses originate from path dependencies generated by human-environment interactions in the Peruvian Southern Andes. For instance, pastoralists increased livestock mobility within their pastures, created wetlands through irrigation, and introduced agriculture of bitter potatoes. The women agriculturalists modified the productive calendar to adjust agricultural tasks to changes in the rainfall regime; they replaced maize for wheat and fava bean, because these crops are more resistant to cold spells. Agro-pastoralists increase institutional water governance and demand infrastructure to improve efficient water use. Synergies between local and regional adaptive responses to climate change may be led by projects like building irrigation infrastructure and strengthening local resource governance, although there are also disjunctions that limit adaption. Local social ecological systems are adaptive and resilient to multi-scale social environmental disturbances by a malleable forging of former strategies to face change, innovation, polycentric social organization, and a dynamic institutional body that promptly response to change.

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Chapter 1: Introduction

Over the millennia, human presence has generated long-term unintended impacts on Earth (Marsh [1874] 1970; Steffen et al. 2005; Turner II et al. 1990; Thomas Jr. et al. 1956). The swelling transformation of the earth by humankind has been documented by social and environmental historians (Moore 2010; Redman 1999; Worster 1988), geographers and land change scientists (Turner II, Lambin, and Reenberg 2007; Lambin et al. 2001; Denevan 1992; Turner II et al. 1990), among others. Anthropogenic land transformation drives global environmental changes that threaten Earth's life-support systems (Foley et al. 2005; Steffen et al. 2005), affects natural systems (Chapin III et al. 2009; Nelson 2005; Sala et al. 2000) and degrades ecosystem services (Vitousek et al. 1997); all of which, in turn, compromises human well-being (Turner II, Lambin, and Reenberg 2007; Janetos et al. 2005).

The ongoing dominance of the effect of human activities on Earth systems (Steffen et al. 2005) has set natural systems and the services they provide in an unsustainable trajectory (Chapin III et al. 2009; Ostrom, Janssen, and Anderies 2007); as such, it is crucial for a sustainable world to understand the interactions and feedback mechanisms between natural and social systems (Collins et al. 2011; Ostrom 2009a; Kates et al. 2001). Further, it is well accepted that the challenges posed by such a trajectory are best understood by approaches that couple human and environment systems (Collins et al. 2011; Ostrom 2009a) at multiple spatial scales (Schröter et al. 2005; Kates et al. 2001). Human-driven global environmental changes partially determine the social and physical vulnerability of human populations to environmental, political, and social perturbations (Schröter et al. 2005; Brooks 2003; Turner II et al. 2003; Kasperson, Kasperson, and Turner II 1995). Further, it is accepted that developing countries, and particularly the poor and the agrarian populations within developing countries, are more vulnerable to global change than developed countries or wealthy, urban populations (Allison et al. 2009; Scheneider et al. 2007; Kates et al. 2001). In these countries, the vulnerability stems from: 1) the direct dependency of the agrarian population on the biophysical landscape; and 2) the lack of economic resources to ameliorate the effects of global change (Turner unpublished).

This dissertation studies an agrarian population in, arguably, one of the poorest regions of Peru. In so doing, this dissertation analyzes how humans and their environment respond to three exogenous disturbances: climate change, political change and social change. The disturbance-response couple occurred over different time periods (See Fig. 1.1), and is analyzed at three nested levels (Fig. 1.1): the forelands of the Quelcaya ice cap which is within the territory of the community Quelcaya (Chapter 4); the peasant community Quelcaya (Chapter 5); and the Peruvian Southern Andes (Chapter 6). The contribution of this research is threefold: 1) it investigates the responses of vegetation at high altitudes to climate change (Chapter 4); 2) it improves our understanding of pastoralism as a social-ecological system that, over multiple time spans, has responded to political, social, and climatic changes (Chapter 5); and 3) it presents the mismatches between the needs of the peasantry—i.e., agriculturalists and agro-pastoralists—and the responses implemented by the regional governments to cope with climate change. Further, it demonstrates how addressing the disjunction between social needs and policy responses offers the possibility of improving adaptive responses to climate change in the Peruvian Southern Andes (Chapter 6).

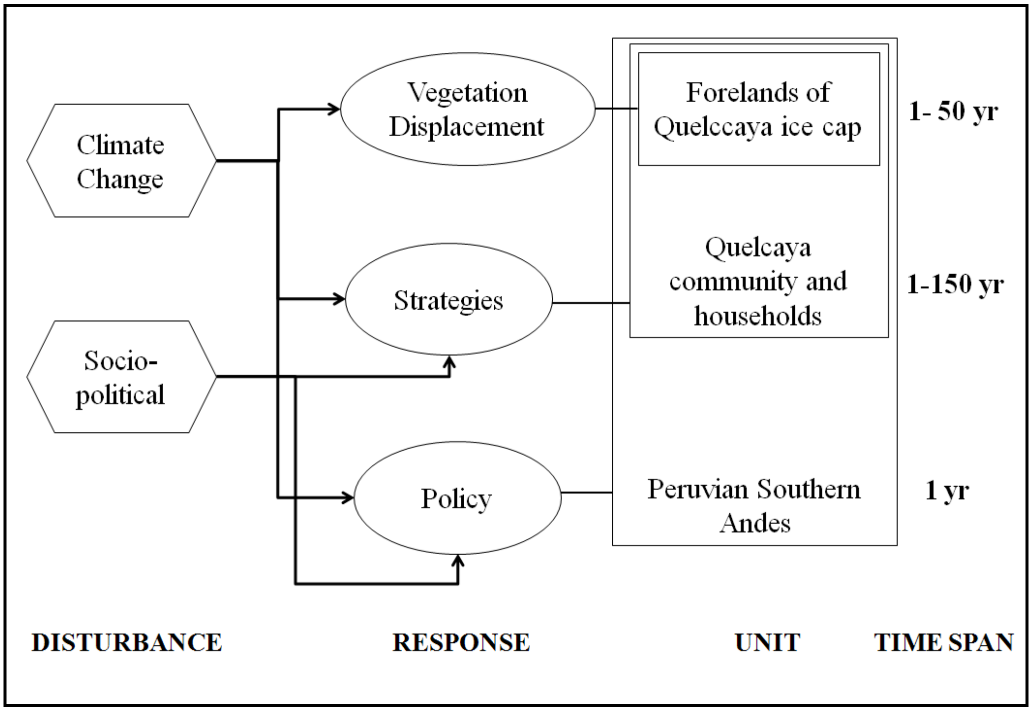

Figure 1.1 Different levels, time spans and units of analysis of this dissertation.

Overall, this dissertation revisits and elaborates the "peasant question", which traditionally has analyzed the effects of capitalist development on peasant society, smallholder agriculture and peasant social movements (Krishnan 2008; Reinhardt 1988; Zamosc 1986), as well as the role of central governments in both solving and recreating agrarian crises (De Janvry 1981). The "peasant question" has focused on social aspects of agriculturalist interactions with capitalism; however, this research enriches the original approach in three ways: 1) by specifically considering how a pastoralist society interacts with sources of change (including the market economy); 2) by understanding the dynamic nature-society relations in the Andes as adaptive interactions of mutual change over time; and 3) by demonstrating that sub-national plans to face climate change in Arequipa, Cusco and Puno, rarely include the practices, knowledge, or needs of peasants. Though this exclusion does not contribute *per se* to the agrarian crises in the Peruvian Southern

Andes, it is a missed opportunity to implement long-lasting responses to climate change and to foster peasant development. Thus, in this research, the "peasant question" includes human-environment interactions; considers processes over multiple spatial and temporal scales; and addresses peasant-government interactions regarding climate change.

PASTORALISM AND CHANGE

Change is perhaps the only constant for pastoralist societies. For centuries, pastoralist systems have responded to social, climatic, political and ecological changes (Galvin 2009; Ash and Sttaford Smith 2003; Fratkin 1997). These processes were fundamentally external to the systems (Markakis 2004; FAO 2001; Khazanov and Wink 2001; Dyson-Hudson and Dyson-Hudson 1980) such as colonial administrations (Bolton 2007), the expansion of the agrarian frontier (Fratkin 1997; Bassett 1988), Nation-State policies (Næss et al. 2011; Khazanov 1984), and climate change (Næss and Bårdsen 2010; Gillson and Hoffman 2007; Butzer and Helgren 2005).

Responses of pastoralist systems have encompassed a range from flexibility to regime shift. For instance, there is a trend of diversifying of economic activities of pastoralists. In Africa, diversification is achieved through livestock intensification and agriculture (Thornton et al. 2007; Homewood et al. 2001; Little et al. 2001). In Asia, diversification occurs through the caste system, with different castes specializing in different productive activities (Mishra, Prins, and Van Wieren 2003). Further, pastoralists in the Serengeti diversified their source of income with tourism (Homewood et al. 2001), while the Fulbe in Mali have taken up cultivation (Grayzel 1990). Such flexibility, understood "as incremental strategic responses to environmental and economic contingencies" (Sperling and Galaty 1990) led to the concept of a pastoral continuum (Salzman 1980). This concept points out the diverse range of economic activities that pastoralist may be involved in over time, from exclusive pastoralism, to temporary wage labor or farming. Further, migratory patterns have been adapted by choosing new directions as in the case of the Fulbe and Tuareg (Bernus 1990). The Tuareg have also diversified their livestock mobility patterns (Bernus 1990). At the other end of the range of pastoralists responses is the regime shift, understood as a change to a new regime whose characteristics and feedbacks are different than the previous regime (Chapin III, Kofinas, and Folke 2009; Folke et al. 2004).

Sedentarization leads, most likely, to a regime shift in the pastoralist system; because it implies "(…) that stereotypes of thinking, behaviour, a traditional system of values and a traditional way of life must be broken". Further "(…) sedentarization is frequently linked to the specific disintegration of a nomadic society and an essential transformation in its social organization" (Khazanov 1994, p. 199). However, there are also cases in which sedentarization is the other end of an spectrum ranging from specialized pastoralists (Sperling and Galaty 1990) to a diversified economy (For examples of impacts of sedentarization in Kenya see: Fratkin and Roth 2005).

The recent changes in the pastoralist society are driven by the modernization process. This process is occurring in the sedentary societies that have been related to pastoralists for long time (Ginat and Khazanov 1998). There is a complex and changing relationship between pastoralist and sedentary societies that involves dependency and threat. On the one hand the modernization process and the incorporation of pastoralists into sedentary societies threatens the pastoralist way of life; on the other hand, sedentary groups have provided necessary agricultural and craft products to pastoralists for centuries (Roth and Fratkin 2005; Khazanov 1998). It is threatening because pastoralists' military power, independence, and pasturelands are all diminishing. The causes of such declines are the technological achievements of and warfare with sedentary groups, the increase in urban, agriculture and industrial zones, and the development of transportation infrastructure. New national boundaries often split former grassland areas. National policies also encourage the sedentarization of nomads, either directly or by constraining pastoral land use or grassland cover (Kreutzmann 2003). Hence, "pastoralists had to adapt not only to specific natural environments but also to external socio-political and cultural environments" (Khazanov 1998, p. 9). Additionally, increasing sedentarization amongst African pastoralists has diminished their mobility, which in turn, has raised their vulnerability facing droughts (McPeak and Little 2005).

The interactions between pastoralists and external forces have led to changes from communal to private land tenure regimes (Deininger et al. 2011; Lesorogol 2003). In so doing, the communal tenure regime that used to characterize pastoral systems is in decline due to the increasing privatization of grasslands (Deininger et al. 2011; Lesorogol 2003). Individually owned grasslands diminish livestock mobility. Livestock mobility was always a major part of pastoralist risk management strategy (Mishra, Prins, and Van Wieren 2003), thus less mobility increases pastoralists' vulnerability to environmental change (Scoones and Graham 1994). Lack of mobility weakens reciprocal rights between pastoralists and individuals or groups that allowed transit on and use of former communal resources (Galvin 2009). Further, Galvin argues that privatization of grasslands, sedentarization of pastoralists, and diversification of pastoral economic activities are causing the fragmentation of grasslands in Africa, which in turn is impacting institutions and social relations of pastoralists (Galvin 2009).

The trend of economic diversification has generated social stratification that has weakened social relationships (Galvin 2009). The weakening and erosion of institutions hampers pastoral systems access to water and forage for livestock (Woodhouse 2003) and diminishes its adaptive capacity (Galvin 2009; Bassett and Turner 2007; McMichael

1997; Khazanov 1984) to increased climatic variability due to climate change (Christensen et al. 2007; Held et al. 2005). These institutions have been crucial for rangeland governance and for strategies to cope with climatic variability and systems' resilience (Mishra, Prins, and Van Wieren 2003; Woodhouse 2003; Turner 1999).

HIGH ANDEAN PASTORALISM

Pastoralism in the Andes was a neglected topic by social scientists, especially by anthropologists, until the early 1960's (Markakis 2004; Flores Ochoa 1977b, 1968). Most of the existing studies considered pastoralism to be an activity carried out exclusively in Europe, Asia or Africa (Markakis 2004; Salzman 2004; Webster 1973). Further, early studies of pastoralism in America wrongly stated that the only pastoralists in the continent were located in North America and consisted of a group of hunters that became pastoralists only after the introduction of domesticated European animals (Markakis 2004; Flores Ochoa 1977b, 1964). In so doing, social scientists overlooked the chronicles—i.e., written historical record of events and facts, which provide accounts of the herds kept and rearing practices by ethnic groups (Wheeler 1995) in the highlands (for examples of the Southern Andes see: Garcí Diez de San Miguel 1964 [1567-68]; Bertonio 1879 [1612]). Generally, the chronicles provide descriptions of local landscapes and native culture (Butzer 1992) and were written by Spanish officials (de Betanzos 1987; de Cieza de León 1985, 1553), priests (Cobo 1943) and travelers during the sixteenth through nineteenth centuries of colonial rule.

Mishkin's (1946) early observations of high Andean communities that base their economy upon pastoralism in the south central Andes did not attract any further research (Webster 1973). The study of Andean pastoralism really began around mid-1960s with the works of Flores Ochoa (1964) and Nachtigall (1966) in the southern Andes of Peru and the Atacama in Argentina. These publications represent the pioneering efforts to understand and explain the situation of pastoralists as a non-agrarian group that maintains their livelihood in landscapes above 4000 m in elevation. Though these authors agree to the characterization of pastoralism as a livelihood that is independent of the farmers with whom they trade products, these authors disagree on the whether the origin of herding practices are related to cultivators. Nachtigall argued that Andean pastoralism developed out of agriculturalism (Nachtigall 1966), whereas Flores Ochoa claims an independent origin (Flores Ochoa 1968).

These seminal works approached Andean pastoralism using a cultural ecology (Sendón 2005b; Bassett et al. 2003; Sendón 2001; Butzer 1989; Turner II 1989; Steward 1955) or a cultural-behavior (Vayda 1969) framework. Later, Flores Ochoa recognized that a cultural-ecological approach is useful for analyzing herders' adaptations to Andean environmental conditions (1977b). Environmental phenomena and cultural behavior are understood either as part of an integrated Andean pastoralist system, or as a partial cause in the origin or development of the socio-cultural behavior of pastoralists.

The definition of pastoralism has followed several paths. The first emphasized whether the pastoralist economy was market or subsistence. Africanist scholars have argued that pastoralism is a mode of production in which the pastoralist household is one that earns more than 50 percent of its income from raising livestock using unimproved pasture (Markakis 2004). In some instances, the pastoralists' main goal of production is not to produce for the market, but rather to produce for subsistence. In subsistence production, usually small amounts of products are sold in markets to purchase commodities that are not otherwise available. Pastoralism is also an aspect of social identity. For instance, the Fulbe identity consists of three elements: "an inherent identification with cattle, and cattle raising (…); an awareness of their shared identity as

Fulbe, meaning "free cattle people"; and a very conscious purposefully promulgated set of values and accompanying behavioral roles that they themselves call *pulaade*" (Grayzel 1990, p. 36). Other pastoralists define themselves as people "who are sedentarized but plan to resume herding" (Markakis 2004, p. 14).

Other scholars examine pastoralism by emphasizing the relationship between herding practices and the ecosystem. For instance, Salzman defined pastoralism as "the raising of livestock on 'natural' pasture unimproved by human intervention" (Salzman 2004, :1). Through this definition, the author refers to the relationship between nature and pastoralist as a human adaptive process to natural conditions. In so doing, it deemphasizes pastoralism as livelihood. This definition also excludes pastoralists who improve pastures by rotation and irrigation.

Ultimately, high Andean pastoralism is an economic activity that provides a means of subsistence to a group of people either directly by consuming the products of pastoralism (meat) and indirectly by bartering animal products (e.g., meat, live animals, hide) for agrarian products (Flores Ochoa and Kobayashi 2000; Inamura 1986; Orlove 1982). Understanding pastoralism as an economic activity that transforms the landscape in order to provide a means of subsistence emphasizes that mutual transformations between humans and nature are at the core of the adaptations that allow pastoralists to subsist in the face of radical social and environmental changes (Browman 1983; Flores Ochoa 1977a, 1968). Though pastoralism, regardless of what aspect of pastoralism is emphasized as key to identifying a pastoralist society, is an economic system that links nature and society, the link is established by society. In other words, it is the pastoralist society that decides to use the land, and therefore transforms the high Andean landscape to earn its livelihood, all within a wider context of active biophysical and political factors. Through use and transformation, society gives a particular meaning, sense, and value to nature. In this dissertation, the High Andean landscapes are that nature, which is transformed by pastoralist society according to a conscious and predefined purpose: the reproduction of pastoralist society.

As an agent that transforms high Andean landscapes and is in return, transformed by them, high Andean pastoralism is both the crystallization of former mutual transformations of nature and society throughout time and the process that leads to future transformations. This double aspect of pastoralism has the capacity to preserve useful transformations from the past as well as discard and recreate former strategies to adapt to current socio–environmental changes. In order to achieve this purpose, social and ecological adaptation is (and has been) a key process. In this way, pastoralism is understood as an adaptive process to mountain conditions carried out by a human group. Ecological conditions and human needs are the initial elements of the system that interact through pastoralist activities. Applicable modifications to the ecosystem in each particular context constrain future human-nature interactions, and dynamics at greater scales (for example: climate change and National policies) disturb or stress the pastoralist system.

High Andean landscapes are constantly shaped and reshaped by social transformation of nature and the natural processes occurring beyond human control from global to local levels (Young 2008; Zimmerer 1999). Adaptation to high Andean landscapes is a complex process that requires physiological changes of the adapting species (e.g., Cárdenas and Villfuerte 2003; León-Velarde S. and Monge-C 2003b; Monge-C and León-Velarde S 2003). Further human adaptation required, for example, changes in their social organization and institutions, mobile households, and stock-breed specializations. The use of artificial wetlands, irrigated pasture, and domesticated animals are the main ways that pastoralists have transformed the physical landscape to make the Andean ecosystems support its livelihood.

High Andean pastoralist society

Pastoralist society has undergone a social adaptation process itself. Pastoralists have to organize themselves to use high Andean pastures, have to create institutions for social control, have to divide labor among household members, have to cooperate amongst households, and have to form networks within and beyond the pastoralist group (Orlove and Custred 1980). Further, high Andean pastoralism is a social institution that encompasses: 1) social organization of households, extended families and communities; 2) land tenure systems combining common property and family usufruct of pastures; 3) land use of pastures based on access to grazing areas and livestock mobility; and 4) long-standing relations with individuals outside the pastoralist community.

Andean herders live above 4000m of elevation in *campesino* (peasant) communities that have no agriculture. Other characteristics of herder is that they: 1) survive raising mixed herds, which are composed of alpaca (*Lama pacos* L.), llama (*Lama glama* L.) and sheep; 2) use products from these herds to barter for the agricultural products necessary for survival (this requires traveling by foot for several days) (Ricard Lanata and Valdivia Corrales 2009; Inamura 1986); and 3) sometimes sell their labor force as seasonal workers (Gil Montero 2004; Masuda 1981). The land tenure system is characterized by the common property of pasture, mainly located on poor soils that are dependent on rain for irrigation (Browman 1983; Orlove 1982). Therefore, livestock and pastures are key elements in herders' productive system (Postigo, Young, and Crews 2008).

Murra (2002, 1975, 1965) developed an ethno-historical approach to pastoralists, treating them as an important specialized group that existed before the times of the Inka State. Pastoralists, at that time, were not only travelers, but also merchants who bartered livestock-derived products (such as meat and wool) for goods from different ecological zones (such as maize, coca, etc.) and supplied wool to weavers in the coast. Because of this role as merchants, pastoralists were a key element within the pattern of verticality (Browman 1974), also known as control over the maximum number of ecological zones (Murra 1975).

Pastoralist systems are flexible. Mobility, grassland use, and market involvement are relevant variables to understanding a pastoralist productive system (Browman 1987a). The interactions with these variables have made pastoralist society either nomadic or transhumant. Current Andean herding mobility patterns do not cover as large an altitudinal gradient as agriculturalists. As such, it constitutes not only a limited version of the model developed by Murra (2002), but also an adaptation to mobility constraints caused by sociopolitical changes (Browman 1987a, 1974). These changes confine pastoralists to grazing their livestock on pastures under family control, which are located within bounded communities. Considering the limited mobility of the herd and the need to return the herd to the original starting point each day, this pattern can be referred to as transhumance (Browman 1987a; Orlove 1982; Orlove and Custred 1980; Browman 1974; Webster 1973). It is the case that such a pattern is still present among some pastoralist societies in Africa and Asia (Markakis 2004; Salzman 2004), Europe (For the case of Norway see: Næss et al. 2011; and for the case of Spain see: Olea and Mateo-Tomás 2009; Butzer and Butzer 1995) and the western US (Huntsinger, Forero, and Sulak 2010). However, there are open ranching pastoralist systems (e.g., US) in which anyone can purchase land and community membership is not a prerequisite to acquire land. In these systems, the goal of production is to produce goods for the market economy (Markakis 2004).

Though mobility among high Andean pastoralists is limited to shorter distances than pastoralists in Asia, high Andean pastoralism (Browman 1974; Webster 1973) shares characteristics with Asian pastoral nomadism (Khazanov 1984). The shared characteristics are: 1) pastoralism is the main economic activity; 2) grasslands are used extensively to maintain herds year round using a system of free-range grazing without the use of stables; 3) periodic mobility, within or between specific grazing territories, is utilized and is based on pastoral economic needs; and 4) production is oriented towards subsistence.

Mobility in high Andean pastoralism is primarily seasonal, related to the rainy and dry seasons. The grazing area chosen also will depend on the suitability of available pasturelands (Postigo, Young, and Crews 2008; McCorkle 1987). For instance, ideally, pastures used during the dry season—June to December—are located at higher elevations than sites used in the rainy season because dry–season pastures generally have other sources of irrigation such as springs and the runoff of melting glaciers. The rainy-season pastures are located at lower elevations which prevents newborns—born in December and January, at the beginning of the rainy season—from grazing in the higher pastures that have harsher weather conditions and more boggy sites where young animals can drown. Herding in various grazing sites requires that herders have (at least) a main house located between the seasonal pasturelands, and one small temporary hut in each pastureland (Orlove and Custred 1980). The herders' mobility patterns are limited by which pastures are under household control and by the borders of the community. For example, in a case in Huancavelica, while the community had a fixed outer border, internally, the land was redistributed periodically—allocating pastures for new households—thereby changing the access to pasturelands of each particular household based on community needs (Postigo, Young, and Crews 2008).

Herders travel with llama flocks beyond community borders in the dry season to inter Andean valleys—e.g., the surrounding areas of Lake Titicaca (Orlove 1986), Cusco and Apurimac (Ricard Lanata and Valdivia Corrales 2009) as well as to the coastal lowlands of Arequipa, Moquegua and Tacna (Inamura 1986; Masuda 1981). The main purpose of these trips is to exchange pastoralist products (fiber, goods, dry meat, and hide) for crops (grains and tubers) and manufactured commodities (e.g., salt). Generally, this travel is the men's duty and, usually, takes more than seven days, walking between fifteen and twenty km. per day while leading between fifteen to thirty llamas per herder. This periodic contact of herders with the agriculturalists' world has led to the establishment of ceremonial kinship between pastoralists and agriculturalists, developing social relationships that allow constant access to the agricultural products and to social networks in other ecological zones (Sendón 2005b, 2003; Golte 1992; Mossbrucker 1990; Browman 1987a).

The ancient trade between pastoralists and agriculturalists (Gil Montero 2004; Núñez and Dillehay 1998) is not the only commercial relationship the pastoralists engage in. Andean herders have been involved in market relations since the late XVIII century, though selling alpaca fiber to the British textile industry (Jacobsen 1993; Burga and Reátegui 1981; Thorp and Bertram 1978). The fiber sold to the international wool market was produced by a natural economy—based on internal reciprocity and exchange of goods and labor—but this economy was open to monetary transactions (Block 2003). That social relations not mediated by money is crucial as it gives herders yet another way to be resilient to fiber price fluctuations and a way to cope with the surplus rate of extraction determined by international commodity brokers (Orlove 1977).

Domestication of South American camelids

Living at 4000 m elevation requires pastoralists to adapt to their environment and results in turn in their transforming it. In order to live in this context, society uses as many natural resources in the most efficient fashion possible (Moseley 2001; Browman 1983; Flores Ochoa 1968). The domestication of camelids is one of the most important transformations carried out by the pastoralist system in its long-term adaptive process to the highlands (Izeta 2008). Domestication is a socially-driven process that involves physiological and genetic changes in the animal. Herders had to learn herding and animal behavior and diet. In addition, herders had to learn about threats to the flock that may come from the landscape, environmental conditions, or from the presence of predators.

The two domesticated South American Camelids are alpaca and llama (Kadwell et al. 2001; Wheeler 1995). The alpaca is an important element in herders' life, both as a product of the domestication process and as a resource managed through social relationships developed by each household:

> The most important animal in this region [the Peruvian Southern Andes] is the alpaca, since (…) human social development is possible at these altitudes in large measure because of these animals. Many important aspects of the culture revolve around or are related to the alpaca, its care, and the products it yields. The alpaca and the llama (Lama glama), mammals native to the highlands, were domesticated by pre-Columbian man in the Andes (Flores Ochoa 1979, :25).

The llama is a service provider in the household economy of herders. The llama's main role is as a beast of burden (Murra 1965). Moreover, wool for ropes and meat for *charqui*—form of jerky made from dried and salted meat—are obtained from llama. In times of extreme scarcity, llamas will be slaughtered to consume their meat.

Camelids long have been an important resource for Andean people (Moseley 2001; Browman 1983; Gade 1969). It is remarkable the importance of the cervid and the camelid for the productive human occupation of the Andean *puna*—i.e., ecosystem of dry alpine vegetation that lies between 3800 m and the snow-line, night freezes from October to March, and rains from December through March (Bustamante Becerra 2006; Flores Ochoa, Mac Quarrie, and Portús 1995b, 1995a; Flores Ochoa 1977a, 1975; Troll 1968). The importance of the camelid can be summarized in the fact that "Domesticated camelids have been the major animal protein source for much of the Peruvian highlands at least for the past 5000 years" (Shimada, Wing, and Wheeler 1988, p. 136) and complement a diet where the primary calorie source is tuberous crops (Bonnier, Wing, and Wheeler 1988; Moore, Wing, and Wheeler 1988). There are two possible areas of domestication. One is the *puna* of the central Andes where, according to archeological evidence, camelids were domesticated in 2500 - 1750 B.C. (Wheeler 1995; Wheeler Pires-Ferreira, Pires-Ferreira, and Kaulicke 1976). Wild ancestors of alpaca and llama have been part of the High Andean ecosystem for approximately 10,000 years (Moseley 2001; Wheeler 1995; Browman 1989; Gade 1969). Faunal remains found in archaeological sites suggest that these ancestors were half of the game hunted by ancient Peruvian until 7500 years ago. The other most common source of meat for ancient Peruvians came from the huemul deer *Hippocamelus antisensis* (Wheeler 1995; Wing, Vuilleumier, and Monasterio 1986).

The second possible area of domestication is the Andean altiplano (Wheeler 1995). In this region there is evidence of a human imprint from herded animals–i.e., South American camelids—that traces back perhaps 9000 years (Browman 1983). Since 7500 years ago, according to archaeological evidence from Andean highlands (4000-4900 m), camelids started to dominate the hunted group. This suggests that the early population living at high altitudes primarily exploited camelids for survival (Browman 1989; Wheeler, Clutton-Brock, and Grigson 1984; Wheeler Pires-Ferreira, Pires-Ferreira, and Kaulicke 1976), and, as is often the case when a society depends heavily on one species, that they at some point began herding and domesticating camelids (Wheeler 1995; Browman 1989; Pires-Ferreira Wheeler, Pires-Ferreira, and Kaulicke 1976).

Researchers in archaeology and sub-disciplines within the natural sciences have carried out studies around archeological sites concerning human-animal interactions in the Andean regions (Moseley 2001; Baied and Wheeler 1993; Wheeler 1988). Andean archaeology has contributed significantly to the understanding of the domestication of South American camelids (Wheeler 1995; Baied and Wheeler 1993; Browman 1989). The findings from the archeological site of Huánuco Pampa synthesize these contributions: 1) herded animals were crucial to the economy of this population based upon the abundant remains of herded camelids (Wing and Wheeler 1988); 2) based on documentary evidence, most of the camelids in Huánuco Pampa were domesticated; 3) the animal population in Huanuco Pampa was mature, which indicates the primary use was for livestock products, services and breeding stock (Wing and Wheeler 1988); 4) there was an even distribution of mature population of alpaca and llama within the herd, this indicates not only that alpaca and llamas were slaughtered in approximately equal proportions but also that they had different functions—i.e., fiber versus transport (Wing and Wheeler 1988); and 5) pastoralists tended to segregate from the main herd the young segment of the herd (animals three years and younger). This separation was due to young animals' high mortality rates because they "are susceptible to bacterial infections in the confines of crowded corrals" (Wing and Wheeler 1988, p. 169); there is evidence of such high mortality in other archaeological sites in the Andes (Wheeler 1995). Another important fact is "the dominance of native domestic animal and particularly the herd animal" over the wild hunted guanaco (*Lama guanicoe*) and vicuña (*Vicugna vicugna*) (Wing and Wheeler 1988, :170). Despite all these important findings listed above, only a small portion of archaeological studies have occurred above 4000 m. in elevation, which is the primary location of high Andean pastoralists (with the exception of goat herders).

Though sheep were not part of this millennia process of domestication they deserve mention because of the effects of their introduction in the Andes by the Spaniards. Based on administrative documents, it is estimated that in a period of a little more than a century of Spaniard arrival (1532), 90% of domestic camelids had disappeared (Wheeler 1995). Herds of alpacas and llamas in the coastal and inter Andean valleys were the first to be decimated, because their grazing lands were used to graze cattle, sheep, and pig. The impact was slower in the *puna*, however. The altitude and harsh climatic conditions were not suitable for the Spanish or for their livestock. As a result, this region became a refuge for native populations of people and livestock. Despite its high elevation and inhospitable landscape, the prolonged wars amongst Spaniards, new diseases introduced through the non-native livestock, and tribute (a form of tax) paid in animals or cash (obtained by selling animals) caused the disappeared of llama and alpaca in the Titicaca basin by 1651 (Wheeler 1995).

Nature-society interactions

Social and biological adaptations are components of the adaptive process of the pastoralist to the limited resources of the highlands, and to the dry alpine vegetation and harsh climatic conditions of the *puna* (Winterhalder and Thomas 1978). The relationships between high Andean nature and herder society are based upon energy flows between the herders, the plants and animals of the *puna,* and the agrarian products of the valleys (Thomas, Baker, and Little 1976). As a result, Andean pastoralism can be modeled as institutionalized behavior, that mediates social and natural factors, characterized by: 1) the adjustment to arid areas, open rangelands, and high altitudes; 2) the impossibility of carrying out crop agriculture; 3) the use of domesticated animals; 4) the need for human practices to adjust to the needs of animals (movement to reach pasturelands, salt, water; protection from predators, etc.); and 5) the use of different strategies to obtain agrarian products (Browman 1987b; Flores Ochoa 1977b).

In this transformative interaction between nature and society, pastoralism is both the link of the interacting parts and a consequence of such interaction. Thousands of years of pastoralism might lead one to consider it a successful adaptation to a high altitude landscape, and as an activity able to sustain permanent human populations under current technological conditions and limited natural resources—vegetation and animals. In order to do so, in the mutual transformation that nature and society have undergone over millennia the *puna* has become the livelihood of pastoralists (Lorna, Susan, and Stacy 1998; Baker and Little 1976; Baker 1969). In so doing, high Andean pastoralists have been transforming the *puna*'s landscape through irrigation of pasture, creation of wetlands, and the introduction of non–native pasture (Postigo, Young, and Crews 2008; Moseley 2001; Palacios Rios and Flores Ochoa 1977). Further, high Andean pastoralism and domestication are, in itself, products of such previous physical transformations and serve as adaptations to living above 4000 m.

ADAPTATION

Pastoralism, nature, and society are related through mutual transformations. Pastoralism fuses nature and society in the high Andes forming a social-ecological system; this linkage would not be possible without transformation. The concept of adaptation used in this dissertation adapts the definition of Moser and Ekstrom (2010, p. 22026) as follows: Adaptation involves changes in social-ecological systems in response to actual and expected impacts of social, political and climate changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, that aim to meet systems goals, and may or may not succeed in moderating harm or exploiting opportunities. However, changes in social or ecological conditions might constitute barriers or limits (for the concepts of barrier and limit see: Moser and Ekstrom 2010) to the system, which in turn might adjust. Hence, this dynamic equilibrium between change and adaptation is always in flux. The fluidity and dynamism are crucial to coping with sudden disturbances that may exceed the system's resilience. Additionally, such disturbances may trigger positive feedbacks that could lead to unpredictable consequences (Chapin III, Kofinas, and Folke 2009; Holling and Gunderson 2002).

In the high Andean pastoral systems, adaptation occurs at multiple stages and at interlinked levels. At the species' level, animals, plants, and humans have to adapt or be adapted to *puna* conditions. Biological transformations of each individual living at high elevation are needed, which express the species' adaptation to highland conditions (León-Velarde S. and Monge-C 2003a; Baker 1969). For instance, in the case of humans, the greater lung capacity of high-altitude natives as compared to lowlanders is an adaptive response that allows highlanders to maintain respiratory functions in high elevation conditions (Brutsaert et al. 2004; Thomas, Ulijaszed, and Huss-Ashmore 1997; Greksa, Spielvogel, and Caceres 1994; Baker 1969). Furthermore, plants and animals adapt or are adapted to high altitude conditions (Monge-C and León-Velarde S 2003; Fagan and Weil 2001; Winterhalder and Thomas 1978; Thomas et al. 1976).

At the inter-species level, alpaca and llama are the products of an on-going organized human effort (i.e., domestication). Animal domestication over the millennia in the Andes and elsewhere illustrates how an inter-species (human-animal) relationship has contributed to making the adaptation of each species possible. In addition, Andean society has only been able to adapt to *puna* because a biological changes of herders occurred while they were transforming the biophysical landscape into their livelihood through domestication, fire, herding, and irrigation (Molinillo and Monasterio 2006; Spehn, Liberman, and Körner 2006; Wing, Vuilleumier, and Monasterio 1986; Winterhalder and Thomas 1978).

Though adaptation to the high Andes has taken thousands of years, change is constant in the Andes. It is the dynamic change-adaptation that shapes and re-shapes the pastoralist social-ecological system. Further, adaptation to high Andean landscapes has been possible because the Andean pastoralist society has been able to respond to old, new, known and unexpected processes caused either by local or external action. Recent change in the Andes is carried out by processes like glacier retreat, wetlands shrink, roads network expansion, villages formation, pasture access limitation, and so on. The pastoralist society must respond (by leaving, dying or adapting) to these new and ongoing processes (e.g., ecological, climatic, political) that are in part beyond its control.

It is in these globally changing conditions that the concept of adaptation has become relevant in new academic fields, from biology and psychology to the social sciences and humanities, in part fostered by the explosive development of climate change both as a discipline and as a uncontested fact (Young et al. 2006; Folke et al. 2005; Orlove 2005; Butzer 1980). The revival of this concept has served to extend inquiries beyond investigating the human adaptive capacity to high altitude (Lorna, Susan, and Stacy 1998) to examining the social capacity of communities and societies to respond to current global changes (Agrawal 2008; Smit and Wandel 2006; Adger 2003), to question the viability of ecosystems in regions facing climatic changes, and to interrogate the relationships between nature and society that have jeopardized physical and biological systems (Bernstein et al. 2007; Rosenzweig et al. 2007; Young et al. 2006; Folke et al.

2005; Millennium Ecosystem Assessment 2005; Falkowski and Tchernov 2004; Rindfuss et al. 2004; Turner II and McCandless 2004; Turner II et al. 2003).

In the spirit of overlapping old and new processes, and interwoven social and ecological realms, this dissertation was conceived to analyze change and continuity of high Andean pastoralism. The following pages are organized in seven chapters. After the introduction, Chapter 2 is the study area description, which introduces the three levels of analysis carried out in this research: the forelands of Quelccaya ice cap; the community of Quelcaya, and the Peruvian Southern Andes (Cusco, Puno, and Arequipa). Chapter 3 presents the methods used to gather and analyze information, from quadrats used to survey high altitude vegetation to interviews with high level sub-national authorities. Chapter 4 shows the changes of the spatial distribution of vegetation on the foreland of Quelccaya ice cap. The fifth chapter is the analysis of how the social system of the community of Quelcaya has responded to social, political and climatic changes over more than a hundred years. Chapter 6 analyzes the responses of agriculturalists, agro-pastoralists, and sub-national authorities to climate change in the Peruvian Southern Andes. Finally, the seventh chapter concludes showing how the high Andean pastoralism social-ecological system has been resilient and adaptive to different types of disturbances and external drivers.

Chapter 2: Study area

The study area focuses on two physical areas and two scales: the peasant community Quelcaya and the Peruvian Southern Andes that surrounds the community. The research presented in Chapters Four (Glacier retreat and vegetation changes at the foreland of Quelccaya Ice Cap) and Five (Responses of the Quelcaya social-ecological system (SES) to social and environmental changes) occurred in Quelcaya, while the research presented in Chapter 6 (Mismatched and synergic actions in institutional responses to climate change in the Peruvian Southern Andes Region) was conducted in the larger area of the Peruvian Southern Andes. In this dissertation, the Peruvian Southern Andes encompasses the departments of Arequipa, Cusco, and Puno. Details about each area are provided in the following sections.

THE PEASANT COMMUNITY QUELCAYA

This research area is defined by the community borders of the Quelcaya community and covers 31,358.26 ha (Fig. 2.1); it is divided into the sectors Huancane, Llapha, and Central. In terms of political-administrative units, Quelcaya is part of the district of Corani in the province of Carabaya in the department of Puno in southern Peru (Fig.2.2). The community has approximately 660 inhabitants and around 105 households. The settlement pattern in Quelcaya is similar to those described for other herders in the Peruvian Sothern Andes (Orlove 1982). Herders live in nuclear families consisting of a married couple and their children; eventually an elderly parent generally joins the household. Each household in Quelcaya tends to use three or more dwellings (depending on the amount of grazing areas they control). While the main house is located in the lowlands—next to the dry season pasture—a secondary house is located near the pasture that is used during the rainy season. The third house is near the pasture used in the dry season. There are 27 *estancias* in Quelcaya—units formed by cluster of houses (from 3 to 13), usually formed by the households of extended family.

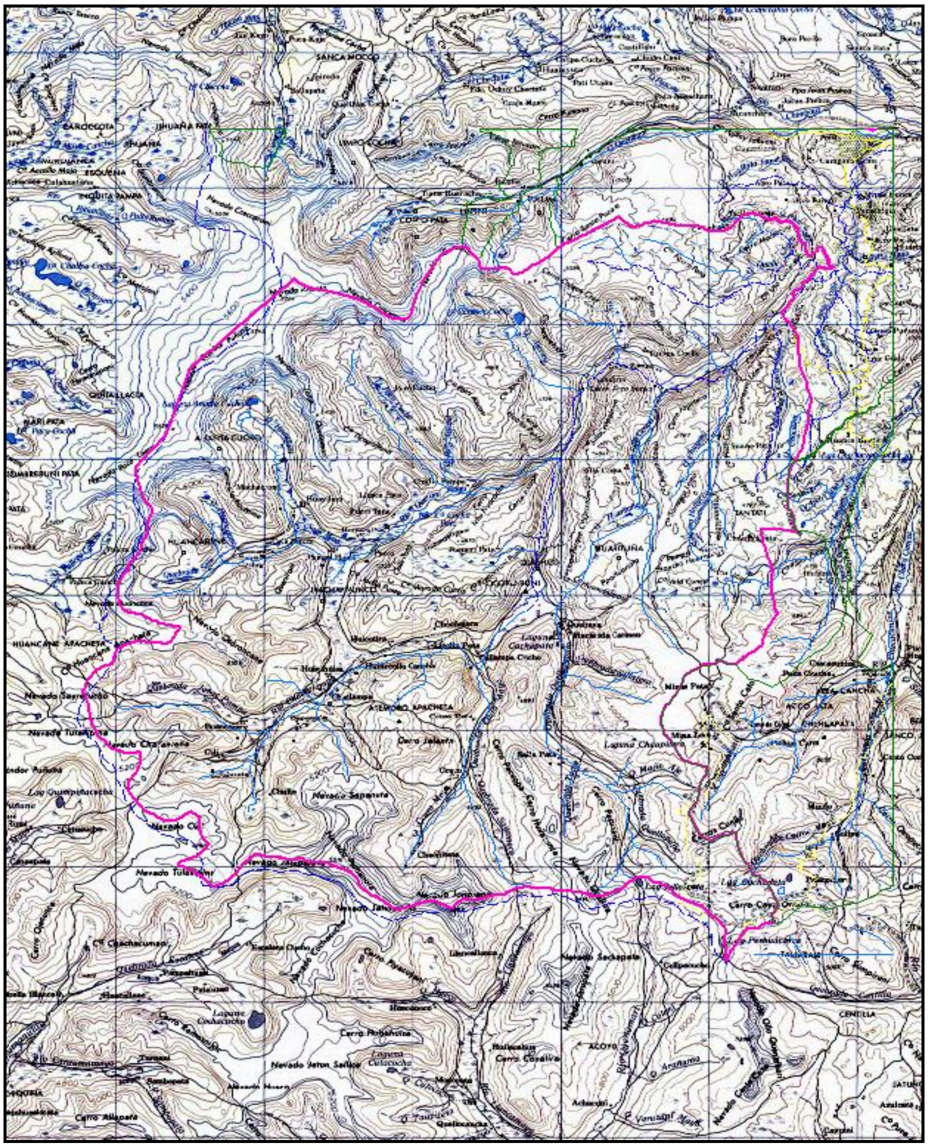

Figure 2.1 The border of the community Quelcaya (pink) on a Peruvian Topographic Map. Scale 1:100000.
Source: COFOPRI-Puno

The village of Quelcaya is built on land that belonged to the hacienda Carmen until 1974; there is still a church of stone and a wing of the old hacienda house. The village serves as a center of political and commercial activities. Here the primary school (with three teachers for first through sixth grades and 79 students, founded in 1940), the health center, community house, offices of community authorities, and the Sunday fair are all located. Previously, only a few families had houses in the village; however, in the last four years, there has been an increase of house construction because a minimum number of houses were needed to install electrical power from the regional electric company. The houses are made of mud bricks, dirt floor, and tin roof. Each house has a faucet outside and there are five sets of gender segregated latrines spread throughout the village.

The physical landscape of Quelcaya is composed of glacier valleys, moraines, valley floors, lakes and rivers. The sides of the valleys are steep slopes, while the valley floors are wide and flat. Hence, the territory of Quelcaya alternates between mountain ridges with undulating flat lands, broken by deep canyons and hills in between. The slopes of the hills are *puna*—dry alpine vegetation (perennial bunch grasses and annual grasses and forbs), or rocks. The flat lands that remain moist during the whole year are *bofedales*, which are associations of perennial vegetation whose most representative species are, among others, *Distichia muscoides*, *Eleocharis albibracteata* (Miranda 1995). *Bofedales* are periodically flooded or irrigated, and are scattered throughout Quelcaya territory. Further, these marshy formations compose tracts along streams running on slopes. These highland wetlands are crucial for grazing alpaca, especially in the dry season when the rain-fed vegetation of the *puna* does not provide enough fodder for the herds (Browman 1990; Orlove 1982).

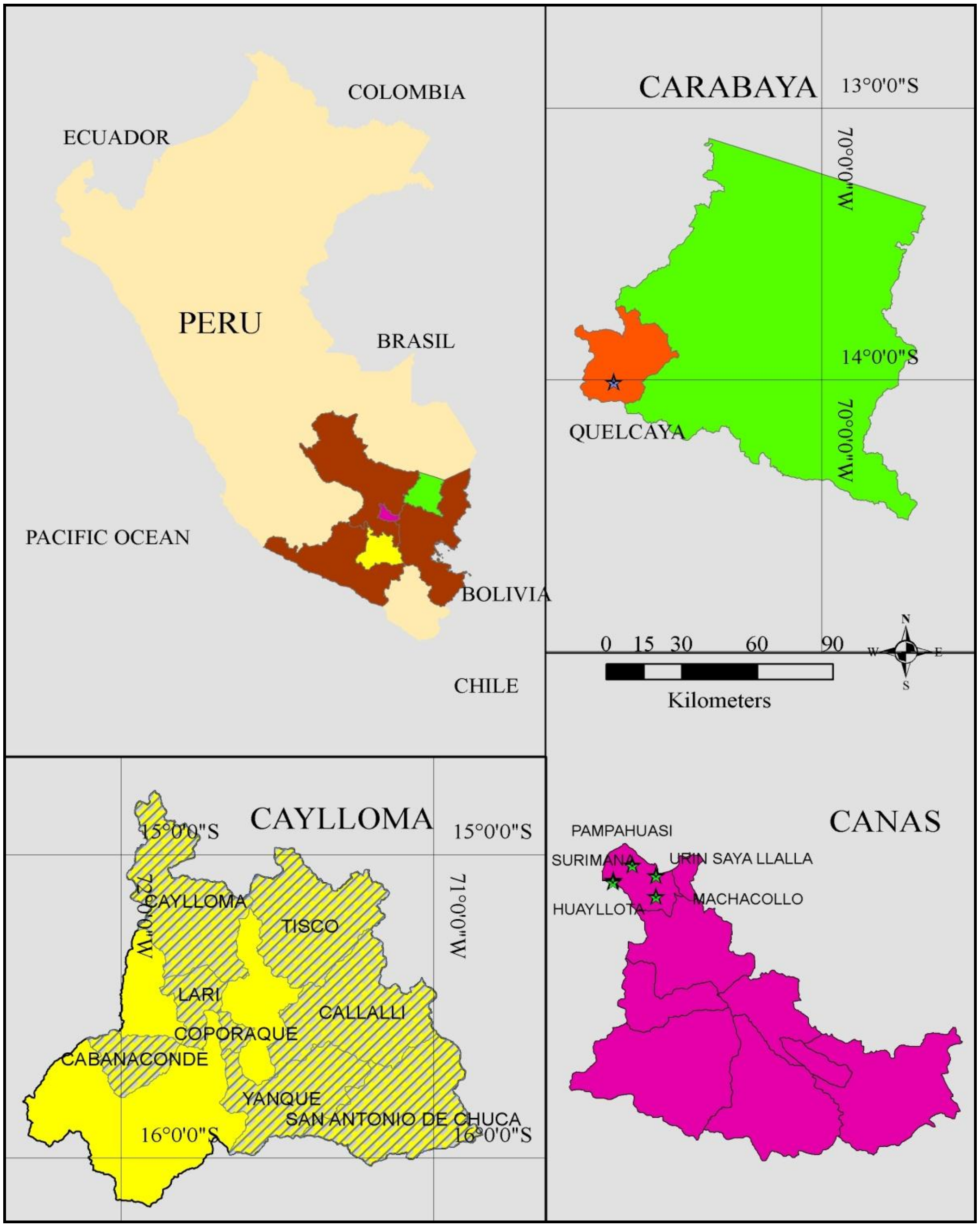

Figure 2.2. Top left: Peru (tan) and the Peruvian Southern Andes (the three departments in brown and provinces in pink, green and yellow). Top right Carabaya province (green), Corani district (orange) and Quelcaya (the community scale). Bottom right Canas provinces and communities visited. Bottom left Caylloma province (yellow) with communities visited with oblique gray lines.

Quelcaya's physical landscape is part of the Altiplano, which is a plateau between the Eastern and Western branches of the Andes that originates in the Vilcanota knot of the Andes Mountains. This plateau is known as Collao, and it was named after the ethnic group that used to populate the area (Markham 1873). The plateau's rich ecology and magnificent landscape have caught the attention of geographers and explorers since the late 1800s (Markham 1903; Markham 1873; Raimondi 1867). Since the late 19th century, the Altiplano's mineral resources have stimulated an enduring interest from mining companies (The New York Times 1889; Markham 1873), with many mining companies exploring and exploiting copper, zinc, gold, silver and uranium deposits (Banco Central de Reserva del Perú- Sucursal Puno 2009).

According to data from the province meteorological station, precipitation (~ 630 mm per year) is seasonal: around 70% of the precipitation occurs between December and March. Throughout the year, temperature ranges from -8.8 to 13.6 °C. Though monthly mean temperatures vary by less than 5°C, diurnal variation is very substantial and shows a seasonal pattern. Thus, in the wet season the minimum daily temperature ranges from 0.9 to 1.9 °C and the maximum daily temperature ranges from 10.6 to 11.7 °C. In the dry season the range is much greater: the range of the minimum temperature is from -8.8 to -5.4 °C and the maximum ranges from 12.1 to 12.4 °C. Hence, during the dry season diurnal temperature variation can reach 21 °C. This climatic pattern is consistent with the climate of lake Sibinacocha, located in the Canchis province (neighbor of Quelcaya) (Schmidt et al. 2008; Nemergut et al. 2007).

Two biotic provinces have been identified in the altiplano: the altoandina (high mountains above 5000 m) and the puna (high tableland from 3300 to 5000m) (Bustamante Becerra 2006; Young et al. 1997). The *puna* can also be characterized as wet *puna* (Troll 1968). Wetlands, grasslands, and bunchgrasses of *Calamagrostis*, *Festuca*, and *Stipa*, are the dominant vegetation types in the *puna*. Further, in the wet *puna*, specifically, species of *Cortaderia* have a significant presence (Young et al. 2007; Young et al. 1997).

The Carabaya mountain range is part of the Eastern branch of the Andes. Located in the Carabaya range is the Quelccaya ice cap—the world's biggest tropical glacier, which is retreating; thus, climate change is a highly relevant process for the study area (Thompson et al. 2006; 1985; Thompson, Hastenrath, and Morales Arnao 1979). Glacier recession has occurred before in this mountain range. Mark and colleagues (2002) used moraine chronology and digital topography to model deglaciation rates. They demonstrated (uncertainties admitted due to the nature of moraine evidence) that several deglaciation processes have happened between events of moraine depositions. Despite the limited comparative power because of the uncertainties, the rates of deglaciation found (39×10^{-5} to $114 \times 10^{-5}\ km^3\ yr^{-1}$) (Mark et al. 2002) are within the range of the rates of Quelccaya ice cap for the 20th century (29×10^{-5} to $220 \times 10^{-5}\ km^3\ yr^{-1}$) (Brecher and Thompson 1993).

Between 1991 and 2005, Quelccaya's biggest glacier outlet has been retreating around 60 m per year (10 times faster than during the 1963-1978 period); this accelerating rate is consistent with the observations from glaciers worldwide: in the Cordillera Blanca in Peru (Thompson et al. 2006; Brecher and Thompson 1993), in Northwestern North America and Southern South America, in Scandinavia, in the European Alps, and in Iceland (Lemke et al. 2007; Rosenzweig et al. 2007; Barry 2006; Kaser et al. 2006; Meier, Dyurgerov, and McCabe 2003; Dyurgerov and Meier 2000; Warren and Aniya 1999). Considering the relevance of the Quelccaya ice cap to glaciers (as the largest tropical glacier), and the speed of glacier retreat, the area chosen for this study (specifically Chapter 4) were the forelands of four glacier outlets on the

Southeastern face of the Quelccaya ice cap, where the elevation ranged from 4800 to 5113 m.

THE SUB-AREA PERUVIAN SOUTHERN ANDES

In this dissertation, the Peruvian Southern Andes encompasses land in the departments of Puno, Arequipa and Cusco (Fig. 2.2). More specifically, the provinces involved in this research were Carabaya (Puno), Caylloma (Arequipa), and Canas (Cusco). The population size of each province is presented in Table 2.1.

Table 2.1. Current population of the provinces visited for this dissertation

Province	Population
Carabaya	73,946
Caylloma	73,718
Canas	38,293

Source: INEI

The region's orography encompasses, from the highest to the lowest parts, glacier peaks and ice-fields, the Altiplano plateau, and Andean mid to high slopes and valleys. Along this altitudinal gradient, several land uses have evolved from Andean land use that predates Spanish conquest (1532), and provides subsistence and commodities (Vos 2010; Zimmerer 1999; Lauer 1993; Murra 1984; Guillet 1981; Brush 1976). In the Altiplano ancient farming took hold around 1600 BC (Paduano et al. 2003; Moseley 2001), while in Arequipa maize was used by 4000 cal yr BP (Perry et al. 2006). The pattern of land use in these mountains was conceptualized by Murra (1967) as 'vertical control' of the maximum number of ecological zones. The purpose of this pattern, ideally, has been to achieve self-sufficiency (Brush 1976) by diversifying the resource base (Vos 2010; Young 2008; Golte 1980) and thereby diminishing risk (Zimmerer 1999; Earls 1989; Browman 1987a). In so doing Andean landscapes need to be recognized as a heterogeneous mosaic of spatially and temporally dynamic land covers and uses (Maxwell 2011; Vos 2010; Young 2009; Young et al. 2007; Zimmerer 1999). Subsistence and market economies have different degrees of co-existence alongside the altitudinal distribution of land uses. Irrigation technology ranges from ditches to dams (Vos 2010; Gelles 2000).

There are four ecological zones in the region, one for pastoralism and the other three are crop zones. In the highest ice-free parts of the study region (above 4000 m), the dominant land use is exclusive pastoralism of mixed herds of alpaca, llama, and sheep (Fig. 2.3). Though the land tenure is characterized by formal communal property, the extended families within the community are the social institutions that control their own pastureland often over centuries. The second zone (3600–4000 m of elevation) is devoted to tuber cultivation in the slopes of the mountains (Fig. 2.4) by agro-pastoralist communities. This agro-pastoralist system consists of (in the higher areas) communal sectoral fallow system: cultivation of potatoes (first year) and barley (second year), and livestock grazing in the fallowing fields (Sendón in press; Zimmerer 1991a; Orlove and Godoy 1986). In the lower areas, agro-pastoralist households often cultivate rain-fed cash crops that are sometimes also irrigated. The third zone (2300–3600 m) is mostly dedicated to cultivate maize, wheat, and barley (for beer production) (Fig. 2.5). The parts dominated by shrublands are used for extensive grazing (Young 2008) and as fuelwood (Maxwell 2011). The fourth zone (500–2300 m) consists of individual (privately owned) small/medium-sized farms engaged in irrigated commercial agriculture of fruits, onion, paprika, and alfalfa for the dairy industry. The use of irrigation requires institutions (i.e., water boards formed by farmers) that regulate access, maintain the irrigation system (e.g., channels, gates), and allocate water (Vos 2010; Boelens et al. 2002; Boelens and Hoogendam 2002; Hendriks 2002; Gelles 2000).

Figure 2.3. Pastoral landscape at 4,400 m in the community of Quelcaya, department of Puno.

Figure 2.4. Harvest of potato in rain-fed communal fallow field at 3800 m in the community of Tantamaco, department of Puno.

Figure 2.5. Third ecological zone. Fields of maize, wheat and barley at 2,900 m in Pisaq, department of Cusco.

The effects of climate change in the Peruvian Southern Andes are perceived through increased frequency and intensity of extreme weather events. In Puno, communities are concerned about droughts, night frosts, floods, wind, and hail (Espillico Mamani and Apaza E. 2009; Sperling et al. 2008). In Cusco, it has been observed that freezing nights are more frequent (Moya and Torres 2008). These documented observations of effects of climate change are consistent with the enhanced variability precipitation registered in the Peru-Bolivia Altiplano (Seth et al. 2010; Valdivia et al. 2010). Furthermore, according to climate projections for the Altiplano, an earlier onset of a more intense rainy season is to be expected, along with an increased occurrence of dry spells (Thibeault, Seth, and Garcia 2010; Valdivia et al. 2010).

In the Peruvian Southern Andes, the institutions involved in the farming systems have different degrees of cohesiveness and actual governance over land and water resources (Vos and del Callejo 2010; Boelens et al. 2002; Gelles 2000; Mitchell and Guillet 1994). There is also great diversity of land governance systems including communal ownership and decision-making that involves smallholders who decide how to use land that is formally owned by the community. At the other end of the continuum are small farmers who own their own land. These institutions have been used to respond to social, political and climatic changes in the Andes. In so doing, they are crucial for the resilience of the Andean social-ecological systems.

Chapter 3: Methods

The methods of this dissertation are diverse and come from both the social and natural sciences. Data was gathered from a wide range of settings, from the forelands of a tropical glacier to the offices of sub-national authorities, and from the huts of herders to community assemblies in the high Andes. Thus, the "subjects" encompass plants and humans, communities and individuals. Such breadth of settings and "subjects" required an array of methods from vegetation sampling to focus groups and social surveys. However, before the application of any research method an authorization from the community was needed.

The first field activity for this dissertation was an interview with two authorities of the *ronda* (night-guard committee) of the peasant community Quelcaya. In this interview, I explained to these two members of the *ronda* my intention of carrying out a research project in their community. The outcome of this initial contact was an authorized visit to a community assembly where I introduced myself, explained my project and the activities that it would involve. I also had to make a case that my presence would benefit the community. This visit took place in 2007 prior to my dissertation fieldwork. Since then, I have visited Quelcaya eight times. The main fieldwork for this dissertation took place in 2008-2009. Before going into further detail of the methods applied, it is worth saying a few words about my background and my own relationship with the community and herders of Quelcaya.

MY RELATION WITH ANDEAN PASTORALISTS

My work in the Peruvian Andes started in 1992 as an undergraduate student of anthropology working as a research assistant for a multidisciplinary team—researchers from edaphology, biology, nutrition, GIS, ecology, and social science—that was investigating integrative management of micro-basins in the Andes. It was in 1998 that I started my work with high Andean pastoralists, which, until 2006, was linked to development projects of non-governmental organizations (NGOs). As part of such work I did my master's thesis in the community of herders Pilpichaca in Huancavelica (Postigo, Young, and Crews 2008). The research in Quelcaya was not mediated by the work of any organization; it was based on a personal and direct relation between the researcher (me) and the herders.

Like everything else in pastoralists' experience, their relationship with me changed over time. The initially cordial distance that marked our relationship changed into familiarity as the herders became used to seeing "the student" (me) wandering and asking questions about the obvious—i.e., herding activities, community governance—organization. My presence was even more accepted when it benefitted the community. For instance, my education and being a native Spanish speaker—unlike community members, who are native Quechua speakers—were of great help in writing (and typing) letters. On another occasion I obtained a donation of medication, from a pharmaceutical laboratory in Arequipa, to diminish the prevalence of anemia among women in the community.

It is likely that the community granted me their trust after a bitter argument with three employees of a mining company carrying out exploratory work in the area. A crew of the company—i.e., a community liaison officer, and two engineers—visited Quelcaya to obtain the permission of the president to measure river flow. Though the crew went into great length explaining how harmless measuring the river was, they neglected to explain the purpose of measuring it. While they were pushing the president to make his decision, I argued that they should inform him of the purpose so he could decide with full information. The mining company evaded disclosing their ulterior motives, so I explained to the president, and to the little group of herders that had congregated by this point of the argument, that the law requires that the flow of rivers used in mining processes should be equal after the mining operation. Thus this measurement was related to a future use of the water of the river of Quelcaya. The president realized that the matter was far more serious than a simple measurement; he relinquished himself from making such decision on his own and instead insisted that it be heard by the entire community assembly. The assembly took place few days later and the community denied the permission requested by the mining company.

Though there was an increase in trust, the relationship with the community was tarnished when my field equipment (two tents, three gps, and a sleeping bag) was stolen in May of 2009. Despite the apologies from the community in an assembly and further investigation to find the responsible of the crime, the following visits to Quelcaya have not yet fully rebuilt the trust that existed prior to the loss of my equipment.

The methods used during my fieldwork in Quelcaya and the Peruvian Southern Andes are explained in the following sections, arranged according to the chapters of this dissertation with which they correspond.

VEGETATION CHANGES

This section presents the methods used to collect and analyze the data for Chapter 4 (Glacier retreat and vegetation changes at the foreland of Quelccaya Ice Cap) of this dissertation. The vegetation data were collected by a team of four people (three assistants and I, including the herder on whose land we were sampling vegetation). A chronosequence approach for sampling species was used, with distance from the glacier front representing time since glacier retreat (Jones and Henry 2003). This provides information on vegetation succession by substituting distance from the glacier lower edge for time (Nemergut et al. 2007; Matthews 1992). For this study, a stratified design was carried out with a regular placement of 113 study plots along eight transects laid out in four glacier outlets across the study region. The study plots consist of a 1-m^2 quadrat (Fig. 3.1) arranged regularly every 40 m along each transect, starting on the lowest edge of the glacier outlet and ending with the last two quadrats of each transect on wetlands, locally called *bofedal*. In doing so, transects encompassed the natural variation of different ground types and slopes. The SE-facing slope aspect was kept constant for the eight transects.

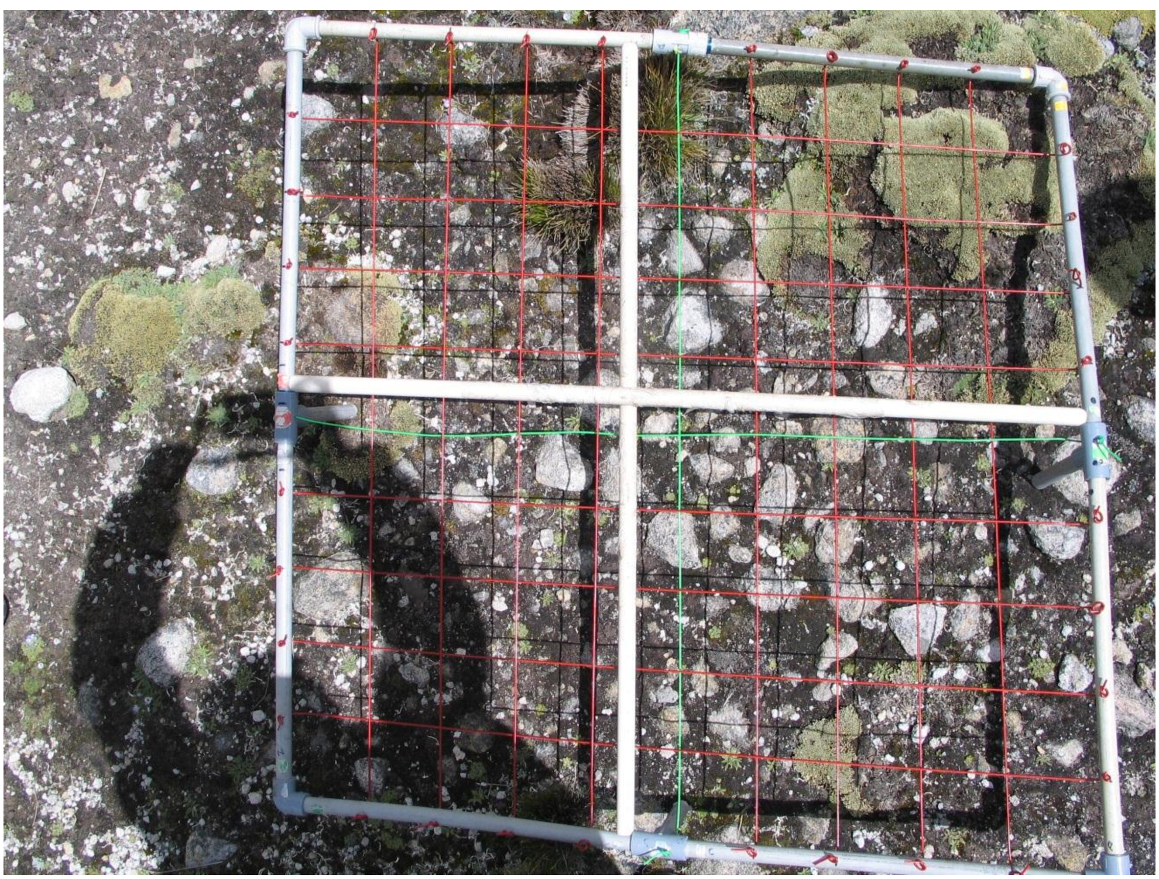

Figure 3.1 Quadrat of 1m^2 used to assess vegetation change along altitudinal gradient

The quadrats cover an altitudinal range between ~5113 to ~ 4830 m., on slopes up to 40%. The quadrats were on geliturbate and bare soil, bare rock, moss, and different degrees of combined soil and stones, the latter encompassing gravel and pebbles. The quadrats ($1m^2$) were divided into 100 squares of 10 cm^2 each. These squares were formed by a grid of cross-wires (see Fig. 3.1) and a sample point was taken at the intersection of each vertical and horizontal wire (Kent and Coker 1999). There were 81 sample points per quadrat. The species under each of these points—called 'hits'—were registered.

Vegetation cover was measured using two methods: 1) by sample point, in this case by the number of 'hits' on the target species; and 2) visual estimate (%) of species cover per quadrat (Elzinga et al. 2009; Kent and Coker 1999). In each quadrat, species name, species cover and the number of 'hits', ground type, elevation, and geographic coordinates were recorded.

A presence/absence matrix was created combining the data collected from sample point and cover estimates; therefore if a species was not hit but was observed in the quadrat it will still be consider present. To avoid having quadrats with no species (i.e., a row of zero in the database) a column 'SpNone' was added so the 15 quadrats with no species will have a value of 1 in this added column. The final presence/absence matrix had 5989 cells (113 quadrats X 53 species), 92.2% of the cells had the value of zero (absence of species). Presence/absence and abundance matrices for transect and glacier outlet were created based upon the vegetation of the quadrats that each of these levels encompassed. Thus data were analyzed at different levels: i) the study area: comparing all possible pairs of quadrats; ii) the outlet level: comparing all possible pairs of quadrats in each outlet, and all possible pairs of outlets, and iii) the transect level: evaluating both all possible pairs of quadrats in each transect, and all possible pairs of transects (Table 3.1 shows the number of quadrats of each unit of analysis). Further, an elevation presence/absence matrix was created presenting quadrats by an elevation belt formed from the highest to the lowest, with an interval for every 30 m in elevation (Table 3.2 presents the number of quadrats per each belt).

Table 3.1. Number of quadrats in each unit of analysis.

Outlet	Transect	Number of quadrats
Outlet 1	Transect 1	17
Outlet 2	Transect 2	8
	Transect 3	12
Outlet 3	Transect 4	12
	Transect 5	10
Outlet 4	Transect 6	20
	Transect 7	16
	Transect 8	18
Total Number of quadrats		113

Table 3.2. Number of quadrats per elevation belt.

	Number of quadrats
Elevation belt 1 (highest)	4
Elevation belt 2	6
Elevation belt 3	13
Elevation belt 4	5
Elevation belt 5	13
Elevation belt 6	28
Elevation belt 7	22
Elevation belt 8	12
Elevation belt 9	4
Elevation belt 10 (lowest)	6

Correlation and Regression Analysis

Vegetation cover, species richness, and the Shannon Index were individually correlated with distance from the glacier and elevation using a rank Spearman ordination (r_s). When tree regression analysis was performed, elevation and distance from the glacier edge were the independent variables, and vegetation cover (%), species richness, and Shannon Index were the dependent variables. Tree regressions were run with each one of the dependent variables and all the possible combinations of them; the best model (optimal tree) was obtained by pruning the fully grown tree in the following way: Cross validation error rates were determined for trees of various size following V-fold cross validation approach (V = 10). Because the V-fold cross validation method produces slightly different trees in each operation, 1000 runs for cross validation were performed. Though the tree size that consistently obtains the minimum cross validation error rate is considered the optimal tree, tree size corresponding to the minimum cross-validation error is not precisely estimated (De'ath and Fabricius 2000; Breiman et al. 1984). Following Breiman et al. (1984), the optimal tree was determined as the smallest tree with error rate within 1 standard error of the minimum. The dependent variables were calculated with PC-ORD 5.10 (McCune and Mefford 2006) and the analysis was performed in R 2.9.1(R Development Core Team 2010).

Heterogeneity

Following Jurasinski and Kreyling (2007), spatial heterogeneity of species composition was analyzed measuring dissimilarity (Koleff, Gaston, and Lennon 2003). Specifically, dissimilarity was measured using the complement of Sorensen’s coefficient similarity ($1\text{-}\beta_{sim}$) between and within each unit of analysis: the whole study area (dissimilarity of all possible pair of quadrats), the outlets (all possible pair of quadrants within an outlet and all possible pair of outlets), the transects (all possible pair of quadrants in a transect and all possible pair of transects), and by elevation belts every 30m of elevation (all possible pair of elevation belts). Further, two components of dissimilarity were analyzed: the mean, and the variance. The former is the mean of the dissimilarities between all possible pairs of elements of the unit of analysis. For instance, the mean dissimilarity of outlets is the mean of the dissimilarities produced by the distance between all possible pair of outlets (Jurasinski and Kreyling 2007). The variance is the deviation of each dissimilarity value from the mean; it gives the spread of dissimilarity values around the mean. (Jurasinski and Kreyling 2007). The higher the variance the more heterogeneous the calculated dissimilarities are between the element and the rest of the unit of analysis.

Non-metric multidimensional scaling (NMDS) ordination with PC-ORD 5.10 (McCune and Mefford 2006) was carried out to assess the dissimilarity in species composition between all quadrat-to-quadrat comparisons. NMDS ordinates samples in a user defined number of dimensions, resulting in a rank of order of distances as similar as possible to the rank order in the original dataset (Phillips et al. 2003). The distance measure used was the Bray-Curtis (Sorensen) index, widely used in plant community analysis because it preserves sensitivity to the data structure without giving undue weight to outliers (Jurasinski and Kreyling 2007; Phillips et al. 2003; Pykälä 2003). Several preliminary runs of NMDS ordination were performed with different parameters. The first run was done with random starting coordinates, requesting a 6-D (six dimensions) solution and reducing dimensionality at each cycle to a 1-D solution, a step length of 0.20, an instability criterion of 0.0005, 300 iterations, 30 runs with my real data, and 30 runs with randomized data. Then the best result—the 3-D solution—was selected and its coordinates were the starting point for another ordination with 15 runs with real data, 0.0005 as stability criterion, and 300 iterations. Stress is a major element evaluating the quality of the solution; it assesses the mismatch between the distance measures and the ordination distance. Stress < 20 are considered useful for interpretations (Jurasinski and Kreyling 2007). The stress result of this process was 17.346, and then an ordination was performed using these criteria but with one run with real data with a stress of 17.346.

Additionally, the NMDS ordination was repeated 30 times with Sorensen distance, 100 runs with real data, the maximum number of iterations 500 and 100 randomized runs, and random starting points scaling from four to one dimension (Pykälä 2003). In all the repetitions the 3-D solution was not only recommended but also consistently had a stress of 17.346. Furthermore, a NMDS ordination with the Autorun format was also run to compare its results with the manual ordination previously described, and verified that the best parameters are being used. The results of the Autorun format recommended a 3-D solution of 17.345 stress which is consistent with (but a bit lower) the processes done previously.

The same steps were followed for the NMDS ordination of plots with abundance data; although the 3-D solution was recommended it had a stress of 18.343. The higher stress in the abundance matrix than the presence/absence one explains the greater distance between quadrats in the multi-dimensional real world and the reduced dimensional space of the ordination when abundance is considered rather than zeros and ones indicating absence and presence.

THE PASTORALIST SYSTEM OF QUELCAYA

In order to understand the responses of the Quelcaya pastoralist social-ecological system to political, social, and climatic changes, information was gathered through: a survey; semi-structured interviews; participant observation; focus groups; archival research; and informal conversations. The research team was formed by three research assistants (including a woman sociology student from the community of Quelcaya), two field assistants also from the community, and myself. The survey (see Appendix 1) was applied to 91 (86.6%) households regarding: i) household socio-demographic characteristics; ii) livestock quantity and composition; iii) grazing areas; and iv) perceptions on climatic changes. Twenty-five semi-structured interviews were conducted with key informants and authorities of the community. The semi-structured interviews addressed (see Appendix 2): institutional governance of pastures and water; ii) herding practices and division of labor; iii) perceptions of and responses to climatic changes, and modifications of the institutional arrangements to access and/or control pastures.

Household demographic and socioeconomic characteristics, and household responses to climate change were analyzed to determine whether responses to climate change varied by the household characteristics. Chi-squared tests were used to assess the relationship between sets of categorical variables. For example, whether herders irrigated wetlands in response to droughts (a dichotomous, yes/no variable) and whether anyone in the household had some education (also a dichotomous variable). To assess statistical relationships between continuous variables (e.g., number of grazing areas) and dichotomous variables (e.g., household education level) t-tests were performed.

Participant observations of herding activities were carried out (during both the rainy and dry seasons), community assemblies, Sunday fairs, vicuña round-ups, and a llama caravan to the valley Marcapata (Cusco) (Figure 3.2). The Marcapata valley is a valley of agriculturalists that Quelcaya herders have visited yearly for decades, around July and August (harvest season), to barter and buy their annual supply of maize. In order to do this caravan, a herder and the author herded (on horseback) twenty-two *llamas* from Quelcaya to Sabancay (Marcapata district, province of Quispicanchi in Cusco department) and twenty *llamas* on the way back. This was a six-day journey, crossing over the Andes three times, covering more than 100 km across an elevation range of 4054 to 5216 m.a.s.l. The cargo of each *llama* was weighed to assess the amount of maize obtained in each bartering process.

Figure 3.2 Llama caravan (>5000 m) and road construction (on the left) between Marcapata and Phinaya village, province of Quispicanchi in the department of Cusco.

Nine focus groups were conducted: three with men, three with women (Figure 3.3), and three with people from different cohorts. The focus groups addressed chiefly: i) herding activities and division of labor; ii) household-community relations; iii) perceptions of change in climate, natural hazards, and presence of governmental and non-governmental agencies; iv) changes in land tenure systems; v) social differentiation; and vi) vision of future.

Figure 3.3 Focus group with women in sector Llapha conducted by female research assistant.

Archival research was conducted in the Regional Archive of Puno, and the community archive. The analysis of the documentation found shed light on history of the families' struggles—i.e., trials and formal complaints to authorities—between land owners trying to keep their land from other land owners (*hacendados*). Archival documentation also showed the process of the development of the constitution of the community in the late 1980s, and served to corroborate information obtained in semi-structured interviews on the formation of the community.

THE PERUVIAN SOUTHERN ANDES

Chapter 6 (Mismatched and synergic actions in the institutional responses to climate change in the Peruvian Southern Andes Region) analyses the disjunction and potential synergies between the institutional responses of peasants and regional governments to climate change in the Southern Andean Region. In order to perform this analysis, I interviewed the regional government officials[1] in charge of the Directorates of Environment and Natural Resources, Agrarian Promotion, and Socioeconomic Development, in the departments of Arequipa, Cusco, and Puno. Eight individuals in total were interviewed in the three departments. Though these Directorates are now part of the Regional Governments, they used to be part of National Government's environmental authority and the Ministry of Agriculture. Twelve additional functionaries in charge of programs and units related to natural resources or environmental management were also interviewed. The themes covered in the interviews were: i) what are the impacts of climate change in the department and on peasant farming; ii) how is climate change included in the regional government plans and projects; iii) what is their knowledge of the responses from peasants to effects of climate change.

In the fall of 2009, seventeen (17) peasant communities were visited in the provinces of Carabaya, Caylloma, and Canas in the departments of Puno, Arequipa, and Cusco respectively (See Fig. 2.3). Peasants and farmers' responses to climate change were obtained through 29 semi-structured interviews with community authorities,

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[1] It is noteworthy that departments in Peru are in the process of becoming "regions", which explains why they have "regional" authorities. This is part of the ongoing decentralization that is occurring in the country.

leaders, water board officials, and key informants, as well as 3 focus groups with peasants in Cabanaconde (Arequipa), Tinta (Cusco) (women only) and Quelcaya (Puno). Additional interviews were carried out with representatives of civil society and employees from non-governmental organizations' (NGOs) both in their headquarters and in the field. This group of interviews (with peasants and NGOs employees) addressed the following themes: i) perceptions of climatic changes and its effects; ii) responses to perceived changes and effects from peasants, the regional government, and NGOs; iii) and expectations about actions from the regional government and NGOs to respond to climate change.

Community leaders chose the peasants to be interviewed, while functionaries were interviewed based on their availability. The provinces and the communities were selected following conversations with three NGOs (non-governmental organizations) who operate in the three departments of Peru. *Asociacion Servicios Educativos Rurales* (SER) operates in Puno; Desco is active in Arequipa; and *Asociacion Arariwa* operates in Cusco. The selected communities cover the range of Andean farming systems from mostly agriculturalist to exclusively pastoralists, from land tenure regimes of communal property to individual private property, and from farming systems with traditional technologies (e.g., terraces) to modern systems (e.g., dripping irrigation). By covering this diversity of systems of Andean farming I observed the array of adaptive responses used by peasants and how they vary by the specific farming system (e.g., pastoralists, farmers). Though the selection of communities and provinces was biased towards the NGOs' working areas, their participation was crucial as they provided access to local and regional functionaries, and logistical support in the area. The NGOs' relationships with authorities and presence in the field allowed this fieldwork, which would be extremely difficult otherwise, considering that communities often are suspicious of outsiders, and without a local contact local cooperation is unlikely. To further support the validity of the findings presented in this dissertation, the peasants' responses are compared to results from other studies in the Peruvian Southern Andes (Valdivia et al. 2010; Orlove 2009).

Community members and smallholders will be referred as peasants (Vos 2010); however, I will use 'agriculturalists', 'agro-pastoralists', and 'herders or pastoralists' when differentiation is needed between those whose main livelihood is agriculture (agriculturalists), those whose livelihood is based on a mix of agriculture and raising livestock (agro-pastoralists), and individuals whose livelihood is based exclusively on pastoralism (pastoralists). The term 'farmer' refers to medium-sized commercial farmers; they are independent land owners and are not part of a community in my study area.

Climate data were acquired from the Peruvian National Service of Meteorology and Hydrology (SENAMHI- www.senamhi.gob.pe). The three sets of methods used in this dissertation allowed the understanding of responses from natural, social, and social-ecological systems to exogenous drivers at each one of the levels analyzed. Further, these methods provided data to analyzed relations and feedbacks between levels and processes happening at different temporal scales. The complexity of the issues faced by social-ecological systems requires methods from multiple disciplines and linkages between natural and social sciences.

Chapter 4: Glacier retreat and vegetation changes at the foreland of Quelccaya Ice Cap

GLACIER RETREAT AND VEGETATION CHANGE

The process of glacial retreat renders ice-free areas that expose bare substrate. The creation of bare land—a process also known as nudation—is a driver of succession (Clements 1928, 1916; Cowles 1899). Once land is *nude* it can undergo ecological succession, defined simply, as sequential species change over time (Walker and del Moral 2003; Walker 1999). Researchers of succession have debated over the nature and mechanisms of the process (Callaway and Walker 1997; Glenn-Lewin et al. 1992), and whether it leads to an equilibrium state (Walker 1999; Tilman 1988). One side—the former approach, argues that succession is linear and directional having an ending point at species equilibrium (Odum 1969), whereas the other side—the most current approach—, argues that succession is a process of change that "is not always linear and rarely reaches equilibrium" (Walker and del Moral 2003, p. 6). The latter position implies the multi-trajectory character of succession, where some trajectories are cyclic, convergent, parallel, and where disturbance agency causes the reset or redirection of trajectories of change, meaning that stable endpoints are infrequently achieved (Walker and del Moral 2003; Walker 1999).

Ecological succession has multiple pathways and directions (Glenn-Lewin et al. 1992). Underlying this multiplicity are internal and external forcing mechanisms and processes, the former cause autogenic succession whereas the external forces generate allogenic succession (Glenn-Lewin et al. 1992). In autogenic succession, different plant species colonize, and may compete with each other, facilitate each other, or tolerate each other (Chapin et al. 1994; Wood and del Moral 1987; Walker and Chapin 1986; Connell and Slatyer 1977; Odum 1969; Lawrence 1958). For instance, mountain vegetation responses to climate change are examples of allogenic succession.

Most of the research on climate change effects on mountain vegetation has been carried out in the Northern hemisphere (Dullinger et al. 2007; Jurasinski and Kreyling 2007; Kammer, Schöb, and Choler 2007; Pauli et al. 2007; Grabherr, Gottfried, and Pauli 1994). Further, most of this research has been done in the temperate zone (Walther, Beißner, and Burga 2005; Körner 2003; Grabherr et al. 1995). The first description of vegetation changes on an altitudinal gradient came from the painting *Descriptio Montis Fracty*, a product of K. Gessner's climb of the Pilatus (Luzern, Switzerland) in 1555 (Körner 2003). Three centuries later, the first study of vegetation changes in a glacier foreland was carried out by Coaz in the Rhonegletscher glacier (European Alps) during the summer of 1883 (Matthews 1992). The finding was an increasing amount of species as the terrain had been ice-free for more time, adding up to "(…) a total of 70 species from 18 families on ground deglaciated for no more than 10 years, including 39 on the oldest terrain examined" (Matthews 1992, p. 2). The use of distance from glaciers' foreland instead of time that the land has been ice-free, led Coaz and later researchers to realize that increasing distance from the edge of a receding glacier could represent a chronosequence in ecological development (Matthews 1992).

From a list of other early studies of plant succession in recently deglaciated terrain presented by Matthews (1992), the most influential have been the research done by Cooper (1939, 1931, 1923c, 1923b, 1923a) on Glacier Bay, Alaska, who identified three major vegetation types and provided a chronosequence based on detailed glacier retreat records presenting eight intergraded succession stages (Matthews 1992). For further detail and explanation about Cooper's scheme and methods see Lawrence (1958), Decker (1966), and Reiner and others (1971). Later studies on Glacier Bay showed that no single factor or process fully explains primary succession (Fastie 1995; Chapin et al. 1994). Further, three processes are critical to understand succession: 1. life history traits; 2. competitive interactions; and 3. facilitation. The first "determine patterns of succession [the second] provide the mechanisms for changes in species dominance [and initial site conditions and the third process] influence the rate of change and final state of community composition and productivity" according to Chapin et al. (1994, p. 172).

Grabherr and others (1994) assessed in 1992 the state of vegetation in 26 summits (above 3,000 m) in western Austria and eastern Switzerland and compared it with historical records. The authors found not only an increment in species richness—more pronounced at lower elevations, but also that "upward movement of the alpine-nival flora is an overall trend" (Grabherr, Gottfried, and Pauli 1994, p. 448). Sanz-Elorza et al. (2003) used aerial photographs and climatic data to show the upward shift of woody plants—i.e., *Juniperus communis* ssp. *Alpine* and *Cytisus oromediterraneus*—replacing grassland communities, dominated by *Festuca aragonensis*, due to warming and, possibly to changes in grazing practices in 19th century in the central mountain range of Spain.

Jurasinski and Kreyling (2007) analyzed climate change impacts on high altitude species' heterogeneity in seven summits in the Swiss Alps for the span from 1907–2003. The results showed a homogenization over time characterized by increasing species richness in the summits, despite different trajectories in each summit depending on initial species composition, location and geographical context of each summit. Furthermore, homogenization leads to a lower beta-diversity in the summit region, therefore summits become more similar to each other. Walther and others (2005) analyzed vegetation trends for the periods of 1905-1985 and 1985-2003 in the same area of Swiss Alps finding an increase in species richness on the summits not accompanied by a reduction in high alpine specialist species, and accelerated upward shifts of alpine plants. Though this acceleration occurred since 1985 it "can not be conclusively linked to recent climate warming" (Walther, Beißner, and Burga 2005, p. 545), even though it was synchronic with the warmest decade—i.e., 1990. However, the acceleration between 1985 and 1990 might not completely caused by climate warming.

In the past two decades ecological research has increased in the Qinghai–Tibetan Plateau. This increment stems from the general expansion of global warming research in the plateau, because the area is highly sensitivity to temperature changes and alpine ecosystem responses (Tang et al. 2009; Ohtsuka et al. 2008). Though most of the research has focused on carbon dynamics of alpine ecosystems in the plateau, showing the key role of alpine meadow ecosystems in the regional carbon budget (Kato et al. 2006; Gu et al. 2003) and the inverse relationship between grazing intensity and soil respiration rate due to the lower proportion of root biomass in high intensity grazing sites (Ohtsuka et al. 2008; Cao et al. 2004), there are some studies of plant diversity that are relevant to research on the Andes mountains.

Shimono and others (2010) compared data from transects with records published and those located in databases. The authors used detrended correspondence analysis (DCA), obtaining evidence of the crucial role of altitude and the significant but minor role of latitude and longitude, in species composition in the Qinghai–Tibetan plateau. The first and second axes explained 18.7 and 7.6% of the variance in species data, and "the DCA coordinates on the first axis were significantly correlated with altitude ($R^2 = 0.5$, $P < 0.0001$)" (Shimono et al. 2010, p. 4). Other findings were that whereas average and total number of species has a weak monotonically direct relationship with altitude, they have an inverse relationship with mean annual temperature. Further, more than 50% (77) of the species identified were found at higher altitudes than their previous records.

The accelerated retreat of tropical glaciers since the 1970s has uncovered substrates on which ecological processes are occurring, reinforcing the importance of analyzing vegetation shifts in high altitude landscapes. Yet, research on functional ecology of alpine plants is very limited in the Andes (Halloy 2002) and generally limited in the tropics (Körner 2003). In the latter, the majority of studies of succession have been in "lowland 'old-field to forest' systems" (Sarmiento et al. 2003, p. 64), and experimental work is limited to three areas: 1. Venezuelan paramos; 2. Mount Kenya; and 3. Mt. Wilhelm in New Guinea. For a brief account of the literature on these areas see Körner (2003). The scarcity of research on alpine plants' responses to climate change in the tropics applies, also, to studies of current shifts in species range due to climate change in the Southern tropics (Parmesan 2006), and the very few studies of species changes in mountaintops of these tropical areas (Seimon et al. 2007; Parmesan 2006; Pounds, Fogden, and Campbell 1999; Grabherr, Gottfried, and Pauli 1994).

In the largest glacier outlet of Quelccaya ice cap, glacier recession uncovered fossil plants from at least 5200 years ago (Thompson et al. 2006). Thus, study of primary succession—defined as "species change on substrates with little or no biological legacy" (Walker and del Moral 2003, p. 7) or "on substrates with no prior soil development" (Walker 1999, p. 585), is of particular relevance. In a study in the high–Andes of Huancavelica (Peru), Postigo and others (2008) concluded that ecological processes on newly exposed soil due to glacier retreat have diverse trajectories through tolerance, inhibition, and facilitation in the interactions amongst plants. Further, glacier retreat also causes changes in the amounts of soil moisture and, ground and surface water run-off which can subsequently affect extent and location of pastures used to graze animals that are fundamental to human subsistence. In the study that follows I aim to respond to the questions, what are the changes in vegetation operating at the glacier/pasture boundary?

Which species arrived first during primary succession? In order to respond to these questions I assess the successional trends in an altitudinal range from 5100 to 4800 m. and finding whether distance from the glacier or altitude is the most relevant factor explaining vegetation cover, species richness, and Shannon Index. The assessment is based on observed changes in four glacier outlets, from the edge of the ice to the wetlands, statistical analysis, and a chronosequence perspective.

VEGETATION CHANGE AT THE FORELAND OF QUELCCAYA ICE CAP

Flora

A total of 22 plant families and 52 species of vascular plants were found in the 113 quadrats (see species' list and complete name in Table 4.1). Of the 52 species, 8 were shrubs and the rest were herbaceous. The families with greater number of species were Asteraceae (17) and Poaceae (10), while 15 families (71.4%) had only one species.

Altitudinal Distribution

In this research 52 species were found in the study area (see Table 4.1). Twenty three of these species were observed at higher upper boundary of their recorded range (database and catalogue for Peru's flora (León 2010; Brako and Zarucchi 1993)) (see Table 4.1). Of these 23 species, 4 were observed between 545 to 976 m. higher upper limits than their previously registered; 11 species were found at a higher upper limits ranging from 100 and 500 m than their previously registered, and 8 species were found at a higher upper boundary ranging from 35 to 50 m. than their previously registered upper limit.

Table 4.1. Comparison of Altitudinal Range of this Study's Species and Register Ranges in Previous Studies (León 2010; Brako and Zarucchi 1993)

Especies	**Family**	**Observed in this study**		**Observed in previous studies**	
		Max. Alt	Min. Alt	Max. Alt	Min. Alt
Bougueria nubicola Decne.	Plantaginaceae	5113	4841	4300	3850
Agrostis breviculmis Hitchc.	Poaceae	5113	4829	5000	3000
Calamagrostis ovata (J. Presl) Steud.	Poaceae	5113	4829	5000	4500
Xenophyllum dactylophyllum (Sch. Bip.) V.A. Funk .	Asteraceae	5081	5081	5000	4000
Senecio sp4.	Asteraceae	5081	4886	--	--
Senecio sp5.	Asteraceae	5081	4907	--	--
Senecio nutans Sch. Bip. ex Wedd.	Asteraceae	5075	4886	5300	5000
Baccharis caespitosa (Ruiz & Pav.) Pers.	Asteraceae	5066	4839	5000	3000
Calamagrostis densiflora (Blytt) Müll. Hal. ex Walp.	Poaceae	5066	4839	5000	4500
Mniodes sp.	Asteraceae	5066	4942	5000	3500
Belloa sp.	Asteraceae	5066	4839	--	--
Valeriana nivalis Wedd.	Valerianaceae	5058	4930	5000	4300
Leucheria daucifolia (D. Don) Crisci.	Asteraceae	5053	4952	5000	3500
Senecio serratifolius (Meyen & Walp.) Cuatrec.	Asteraceae	5048	4839	4850	4300
Festuca rigescens (J. Presl) Kunth.	Poaceae	5045	4845	4500	3900
Saxifraga sp.	Saxifragaceae	5045	5009	--	--
Nototriche sulphurea A.W. Hill.	Malvaceae	5036	4937	4700	4100
Alchemilla pinnata J. Rémy.	Rossaceae	5036	4841	5000	3500
Silene sp.	Caryophyllaceae	5036	4886	--	--
Calandrinia acaulis Kunth.	Portulacacea	5035	4947	5000	3000
Polycarpon sp.	Caryophyllaceae	5009	4886	--	--
Pycnophyllum molle Remy.	Caryophyllaceae	4998	4829	5000	4000
Trisetum spicatum (L.) K. Richt.	Poaceae	4992	4970	4500	3000
Geranium sessiliflorum Cav.	Geraniaceae	4992	4829	4680	1500
Perezia sp3.	Asteraceae	4991	4894	--	--

Table 4.1 (continued)

Hypochaeris taraxacoides (Meyen & Walp.) Ball.	Asteraceae	4978	4922	5000	3000
Gnaphalium sp2.	Asteraceae	4978	4829	--	--
Gentiana sedifolia Kunth.	Gentianaceae	4977	4864	5000	3500
Distichia muscoides Nees & Meyen.	Juncaceae	4977	4864	5300	3500
Bartsia serrata Molau.	Orobanchaceae	4976	4854	4000	3000
Erigeron rosulatus Wedd.	Asteraceae	4976	4845	5300	3500
Hypochaeris meyeniana (Walp.) Benth. & Hook. f. ex Griseb.	Asteraceae	4969	4902	4500	2500
Baccharis sp1.	Asteraceae	4965	4841	--	--
Azorella compacta Phil.	Apiaceae	4964	4829	5000	3800
Azorella biloba (Schltdl.) Wedd.	Apiaceae	4962	4962	5000	3200
Melpomene sp.	Polypodiaceae	4962	4872	--	--
Castilleja pumila (Benth.) Wedd.	Scropulariaceae	4957	4839	5000	3500
Polystichum cochleatum (Klotzsch) Hieron.	Dryopteridaceae	4954	4954	--	--
Gentianella sp.	Gentianaceae	4944	4845	--	--
Astragalus uniflorus DC.	Fabaceae	4937	4845	4500	3800
Asplenium triphyllum C. Presl.	Aspleniaceae	4925	4854	4800	2800
Ephedra rupestris Benth.	Ephedraceae	4907	4907	5230	3600
Senecio rhizomatus Rusby.	Asteraceae	4900	4900	4500	3000
Myrosmodes sp.	Orchidaceae	4894	4839	5000	3500
Calamagrostis aff. nitidula	Poaceae	4883	4883	5000	4000
Calamagrostis chrysantha (J. Presl) Steud.	Poaceae	4864	4864	5300	4000
Calamagrostis aff. densiflora	Poaceae	4864	4864	--	--
Aciachne pulvinata Benth.	Poaceae	4853	4829	5000	3000
Calamagrostis jamesonii Steud.	Poaceae	4853	4839	5000	3600
Trichophorum rigidum (Boeck.) Goetgh., Muasya & D.A. Simpson	Cyperaceae	4845	4845	4500	3000
Niphogeton dissecta (Benth.) J.F. Macbr.	Apiaceae	4841	4829	4000	2000
Senecio mandonianus Wedd.	Asteraceae	4841	4841	4900	4200

Table 4.2 summarizes the altitude differences between the upper limit that species were observed in this study and previous upper limit registered.

Table 4.2. Observed Species Altitudinal Difference from Higher Upper Limit Registered in the catalogue of Perú's flora (Brako and Zarucchi 1993) and database (León 2010).

Species	**Altitude Difference (m) in Upper Limit**
Bartsia serrate	976
Niphogeton dissecta	841
Bougueria nubicol	813
Festuca rigescens	545
Trisetum spicatum	492
Hypochaeris meyeniana	469
Astragalus uniflorus	437
Senecio rhizomatus	400
Trichophorum rigidum	345
Nototriche sulphurea	336
Geranium sessiliflorum	312
Senecio serratifolius	198
Asplenium triphyllum	125
Agrostis breviculmis	113
Calamagrostis ovata	113
Xenophyllum dactylophyllum	81
Baccharis caespitosa	66
Calamagrostis densiflora	66
Mniodes sp.	66
Valeriana nivalis	58
Leucheria daucifolia	53
Alchemilla pinnata	36
Calandrinia acaulis	35

The first species that colonized the ice-free substrates were *Agrostis breviculmis*, *Calamagrostis ovata*, and *Bougueria nubicola*, which were found at 5113 m. In this study, these species have shown a wide altitudinal distribution (See Figure 4.1)—284 m for the first two and 272 m for the third.

Ten species were found between 5081 and 5050 m (see Table 4.1), of this group *Xenophyllum dactylophyllum* was only found at 5081 m, thus, it has a narrow altitudinal distribution; all the other species in this group had elevation ranges larger than 100 m.

In the 5050 – 5000 m range there were 8 species (see Table 4.1), *Saxifraga sp*. was the only species with a narrow altitudinal distribution because its lower limit was not below 5000 m.

Between 5000 and 4950 m there were 17 species, three of which are species of narrow altitudinal distribution— *Trisetum spicatum*, *Azorella biloba*, and *Polystichum cochleatum*—whose lower limits were not below 4950 m, and the latter two were found only at 4962 and 4954 m respectively.

There were 5 species in the 4950 – 4900 m range. In this group, no species had an upper elevational distribution expansion larger than 100 m, and 2 species— *Ephedra rupestris* and *Senecio rhizomatus*—had a narrow altitudinal distribution; were only found at 4907 and 4900 m respectively. In the 4900 – 4840 m range, 9 species were found, one of which had 55 m of altitudinal range, while 3 species had ranges of 24, 14, and 12 m and five species had a 0 m altitudinal range. It is possible that some species of this group might be at lower elevation; however, interpretation is limited because no sampling was done below 4840 m (see Figure 4.2).

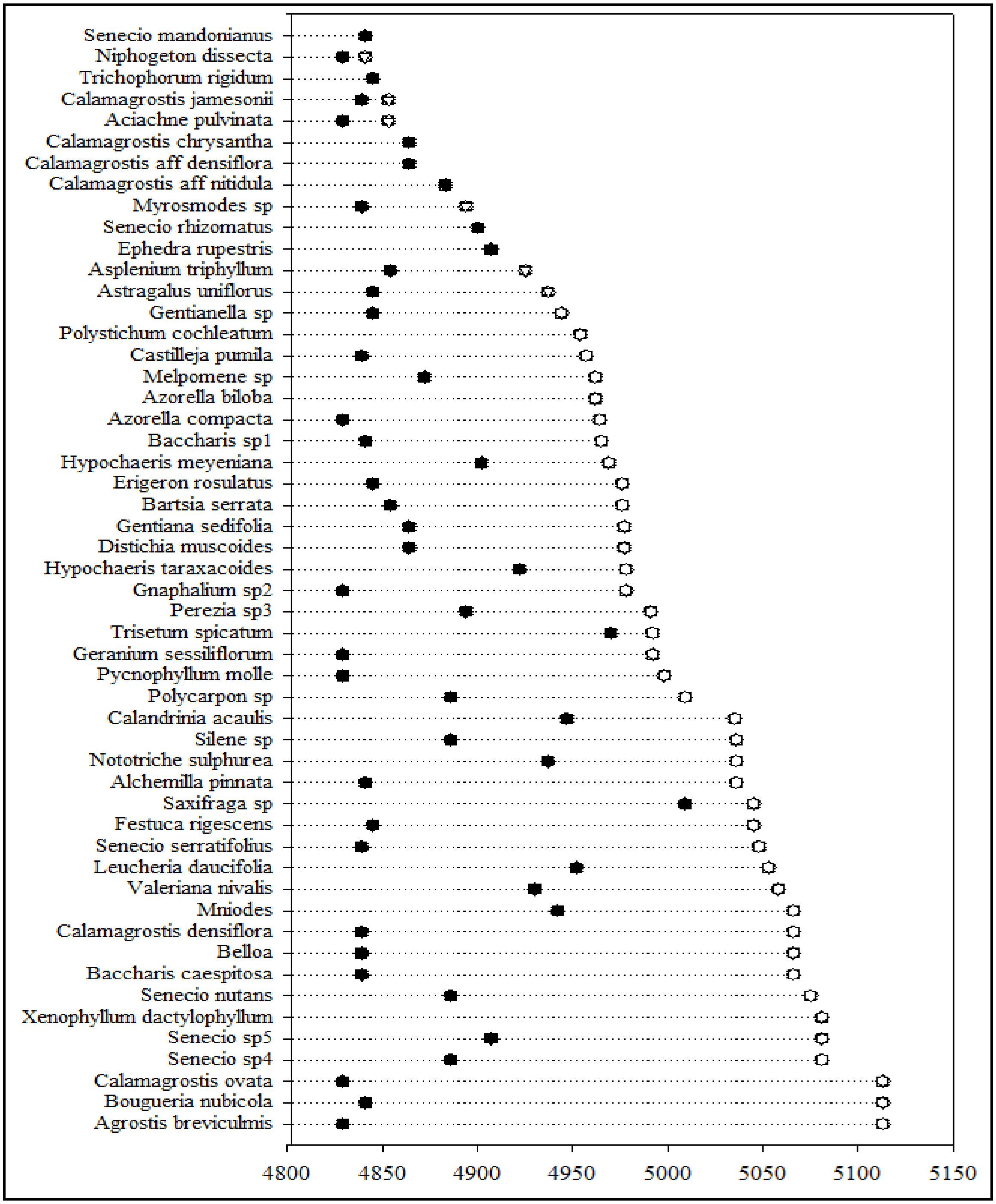

Figure 4.1. Elevation distribution of species in the study area. Black circles indicate lowest elevation recorded in the field sampling, open circles indicate highest. Only one circle indicates that species has the same low and high limit.

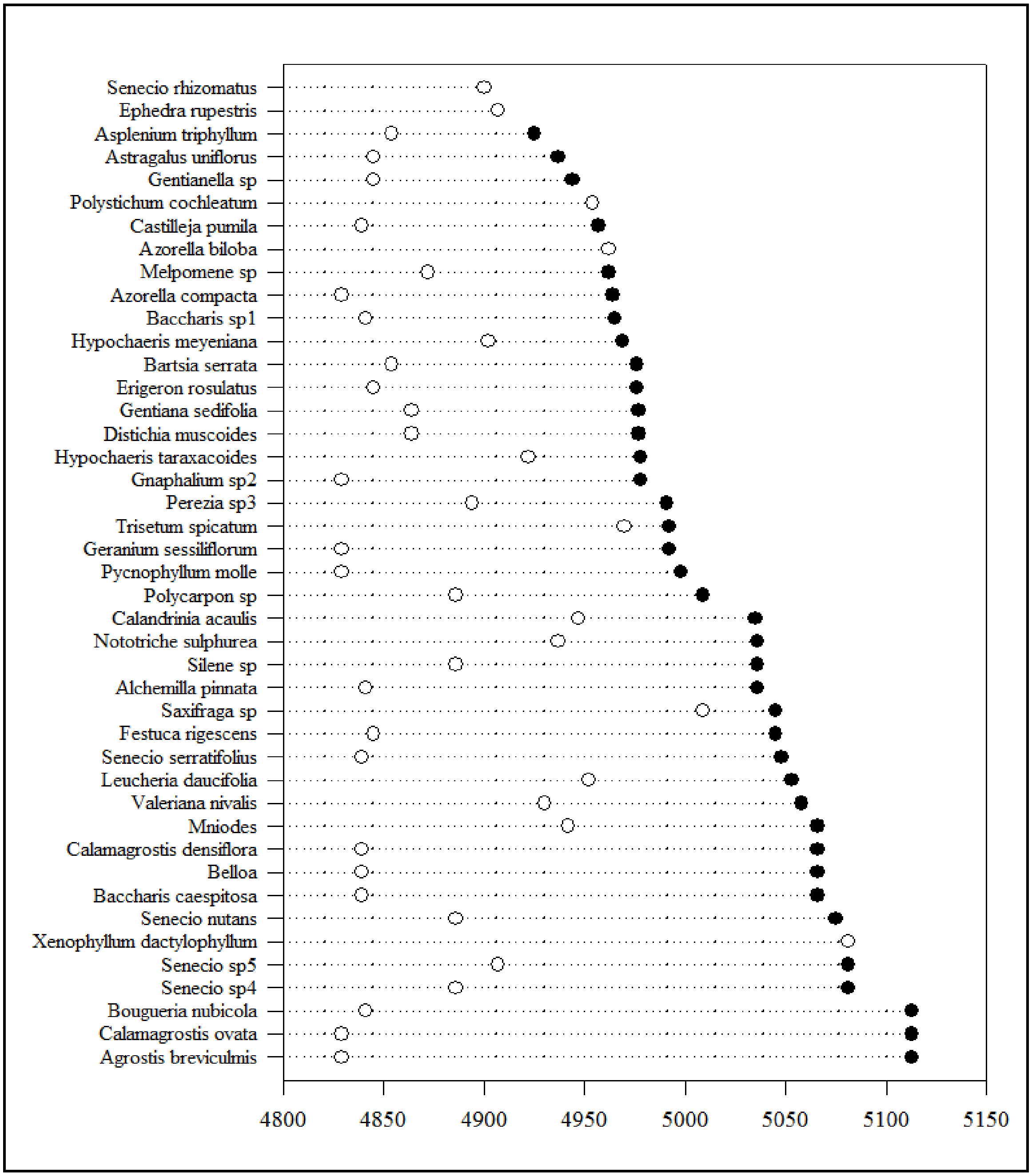

Figure 4.2. Elevation distribution of species whose lower and upper limit were clearly within area sampled in this study (lower limit higher than 4900 m). Open circles indicate highest elevation recorded in the field sampling, black circles indicate highest. Only one circle indicates that species has the same low and high limit.

The species were sorted in four informal groups based on their altitudinal distribution along the transects (Fig. 4.3). The conquerors of ice-free soil, or the first group in the succession, are *Agrostis breviculmis*, *Calamagrostis ovata*, and *Bougueria nubicola*. These species have a wide altitudinal distribution, covering large elevation ranges from as low as the species of the last species group of succession. The large range of cover is clearly a consequence of the shifting upward of the upper limits.

The plant assemblage at the elevation range of 4840 – 4950 m is composed of 14 species that have narrow altitudinal distribution (< 100 m) and they are well established in this area. Following the chronosequence rationale, plants in this group are likely the oldest in the study area, or, in other words, they are the fourth group in the succession.

The third species group in the succession consists of the species between 4950 and 5000 m. These species— with the exception of the three whose lower limits are higher than 4950 m: *Azorella bilova*, *Polystichum cochleatum*, *Trisetum spicatum*—have a wide altitudinal distribution that extends below 4950 m.

The remaining species group is located between 5000 and 5081 m. Sixteen of the 18 species—excluding *Saxifraga sp*. and *Xenophyllum dactylophyllum*— that have expanded their lower limit beyond the 5000 m are overlapping with the species below. It is likely that the second species group had developed mutualistic relations (Stachowicz 2001) with the species that are located upwards.

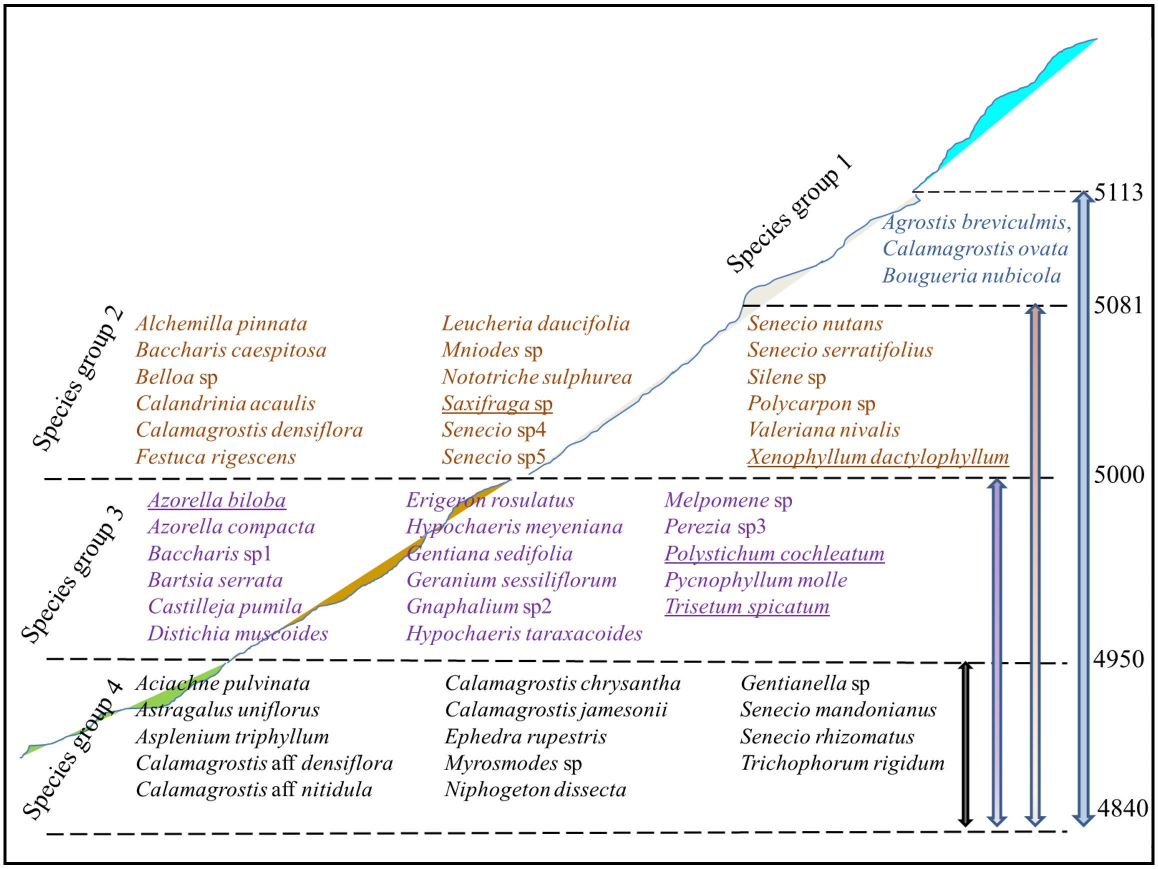

Figure 4.3. Species groups of ecological succession and species' elevation range. Species underlined have narrow altitudinal distribution.

Distance From Glacier and Elevation

Vegetation cover by quadrat, species richness and Shannon Index, are significantly correlated to distance from the glacier with r_s values of 0.515 ($p<0.0000$), 0.549 ($p<0.000$), and 0.481 ($p<0.000$) respectively; therefore the variables increased as the distance from the glacier increased (see Figs. 4.4–4.6).

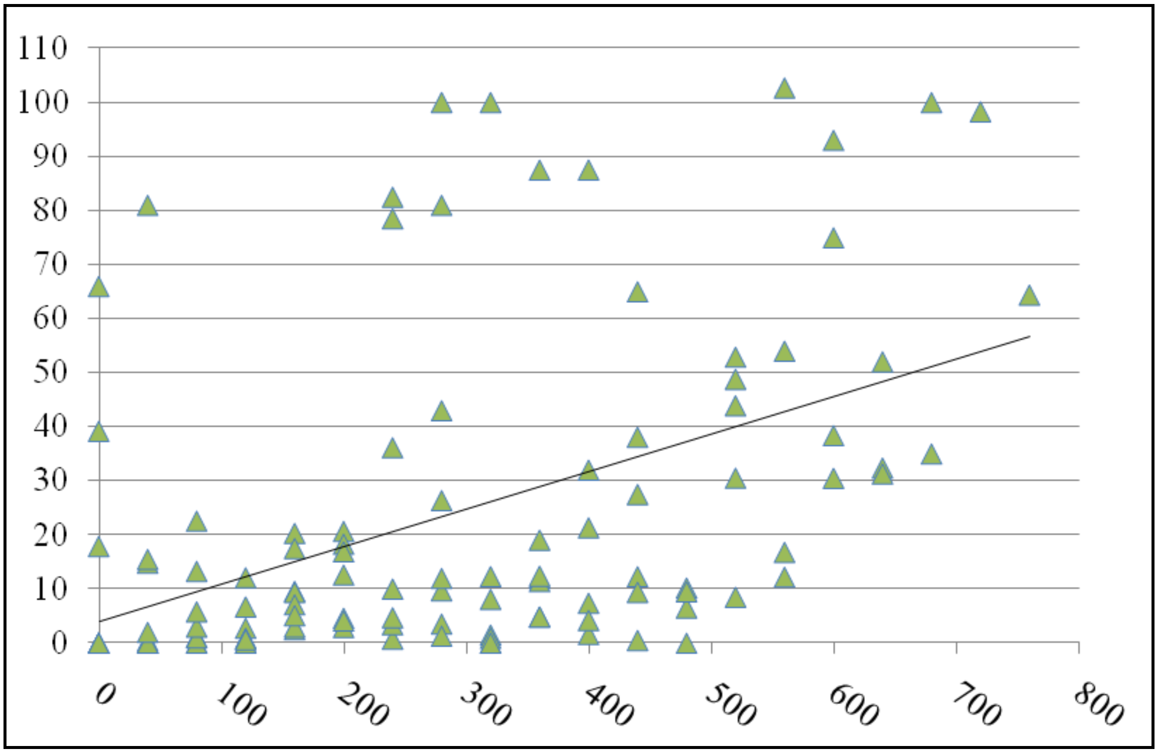

Figure 4.4. Vegetation cover (%) per distance (m) from the glacier edge

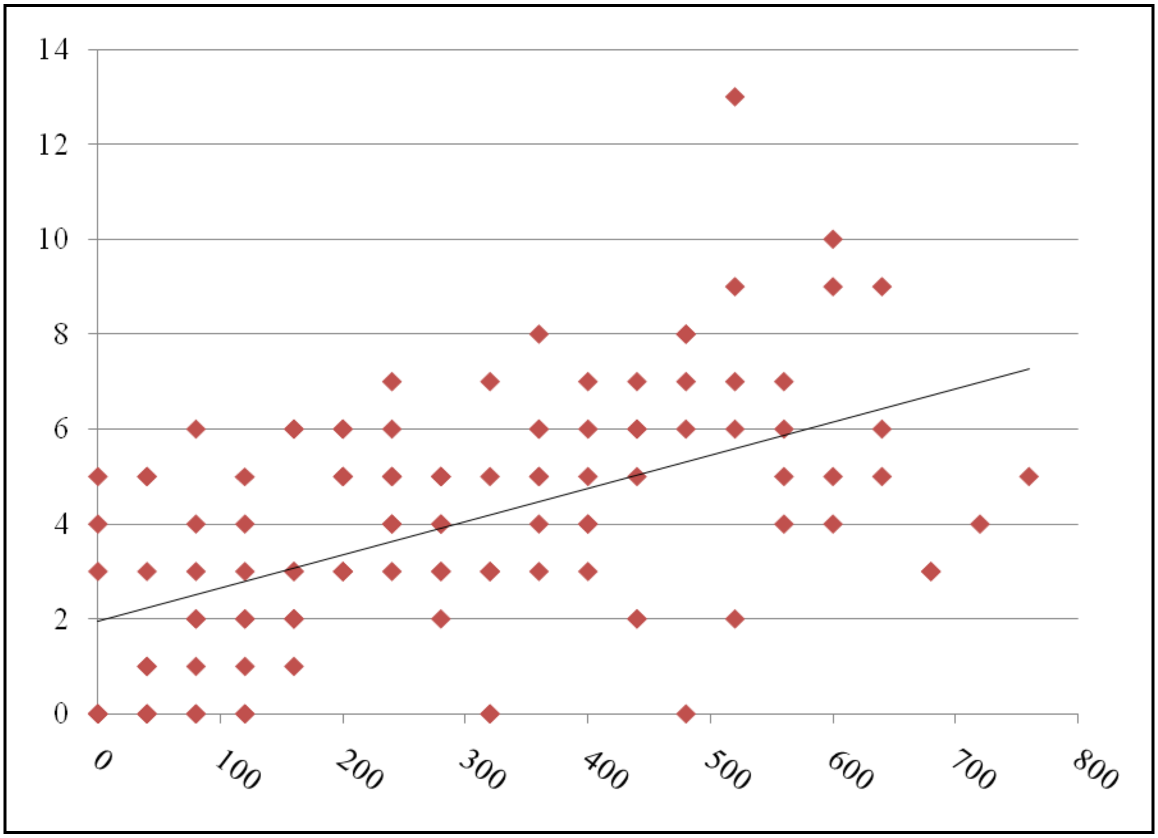

Figure 4.5. Species richness in quadrats per distance (m) from the glacier edge

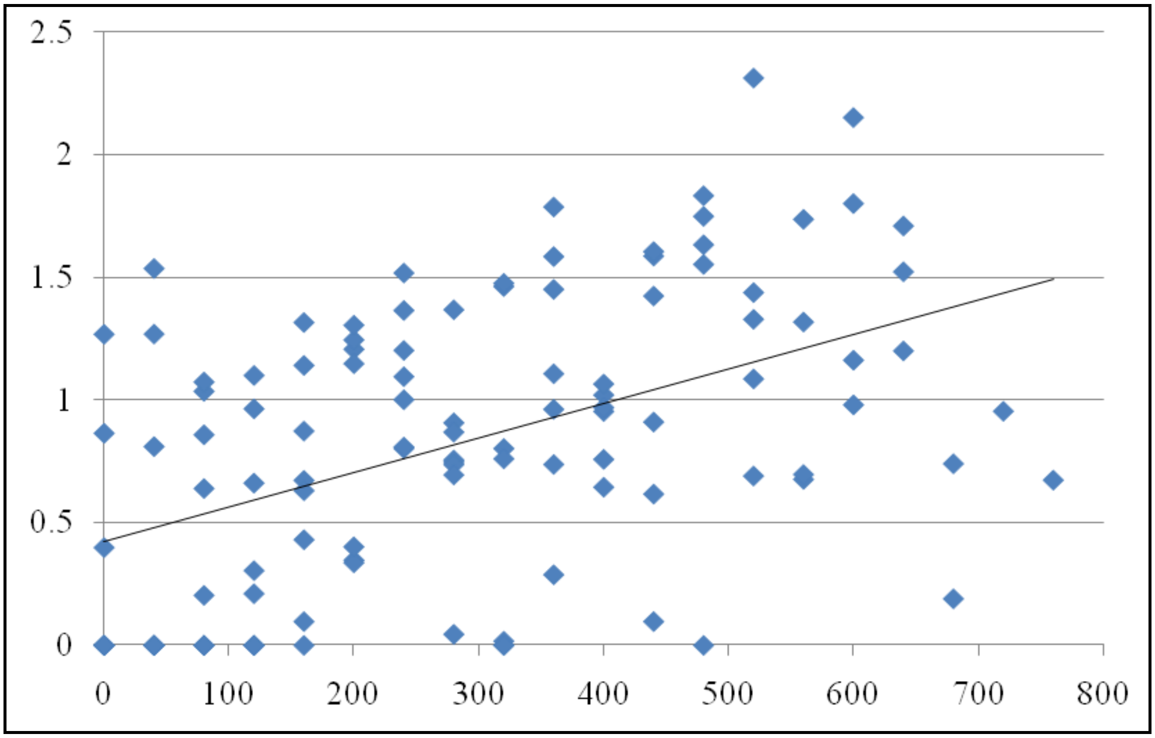

Figure 4.6. Shannon Index in quadrats per distance (m) from the glacier edge

Though vegetation cover, species richness and Shannon Index show a general trend of an inverse relationship with altitude (see Figs. 4.7–4.9), only vegetation cover had a statistically significant ($p<0.000$) correlation ($r_s= -0.355$).

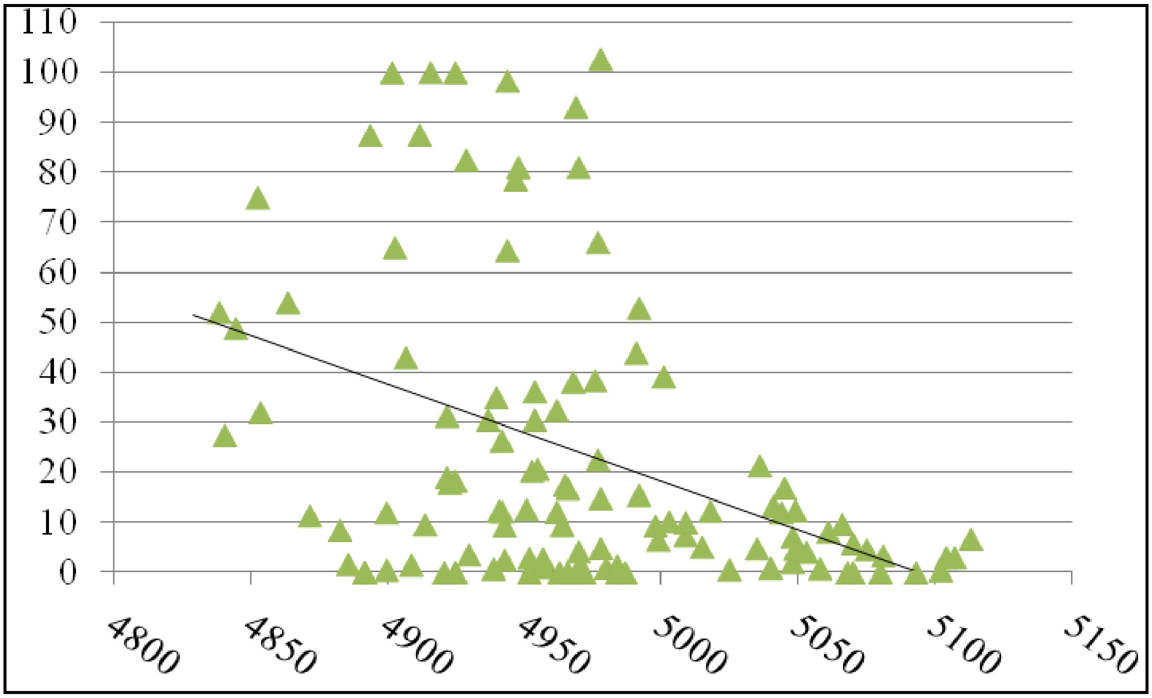

Figure 4.7. Vegetation cover (%) per elevation

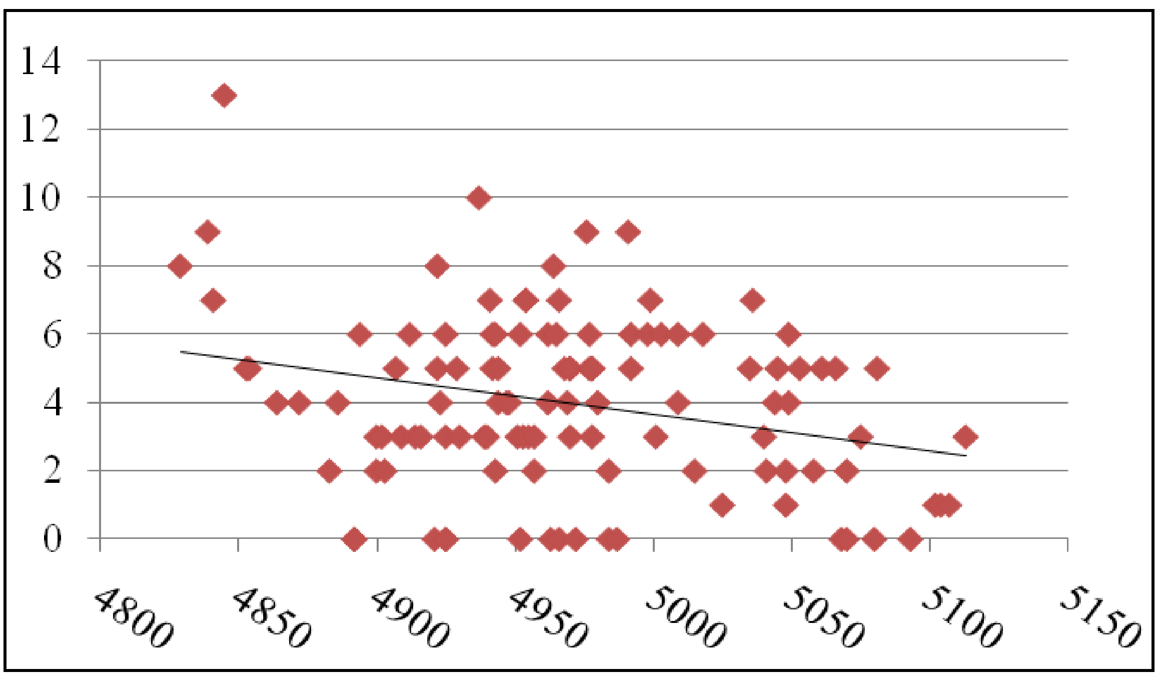

Figure 4.8. Species richness per elevation

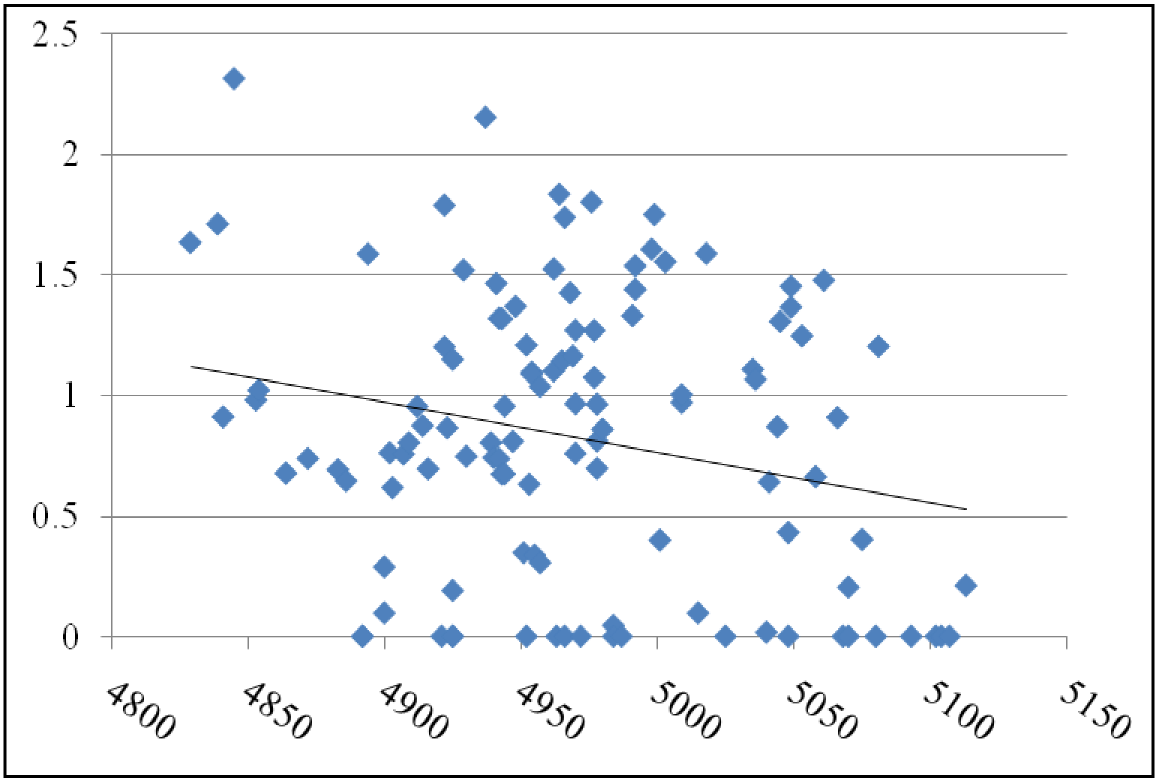

Figure 4.9. Shannon Index per elevation

Vegetation Cover, Species Richness and Shannon Index

Tree regression analysis highlights how species richness is explained by distance from glacier (DFG) and elevation, the two latter make the first two splits in regression tree (Figure 4.10). Overall, these two variables explained half of the total variation in species richness. Regression tree shows that species richness has a direct relation with DFG and an inverse relation with elevation (details given in figure caption). The analysis also shows that DFG is a better predictor of species richness.

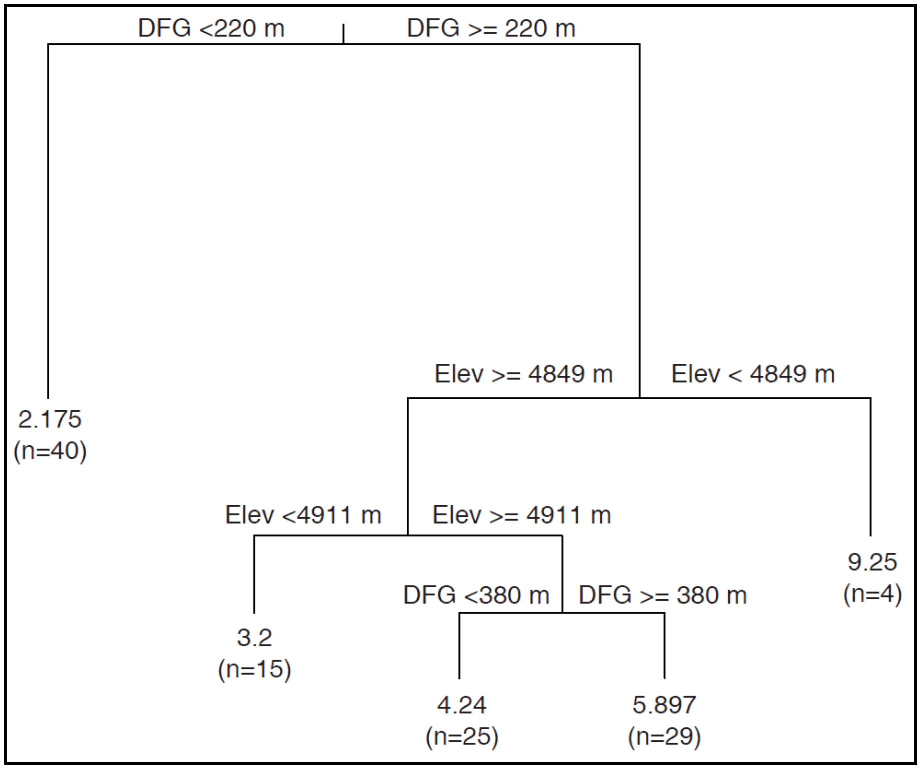

Figure 4.10. Regression tree relating species richness (explanatory variable) to distance from glacier tongue (DFG) and elevation (Elev), potential explanatory variables. Values in terminal node (leaf) are mean of species richness followed in parentheses by number of observations in the cluster. The pruned tree with both explanatory variables explained 49.1% of the variation in species richness. Of the total variance explained, 27.4% was accounted for by the first split and an additional 10.7% variance was accounted for the second split. In total, DFG explained 32.4% and elevation explained 16.7% of the variation in species richness.

Vegetation cover was examined in relation to three explanatory variables: DFG, elevation and species richness. However, the optimal tree captures only DFG as the important predictor of vegetation cover, explaining 17.2% of variation (Figure 4.11). When regression trees are made more complex than optimal, species richness appears in the third split of tree, showing a positive relationship with vegetation cover, and explaining 8.0% of variation in cover.

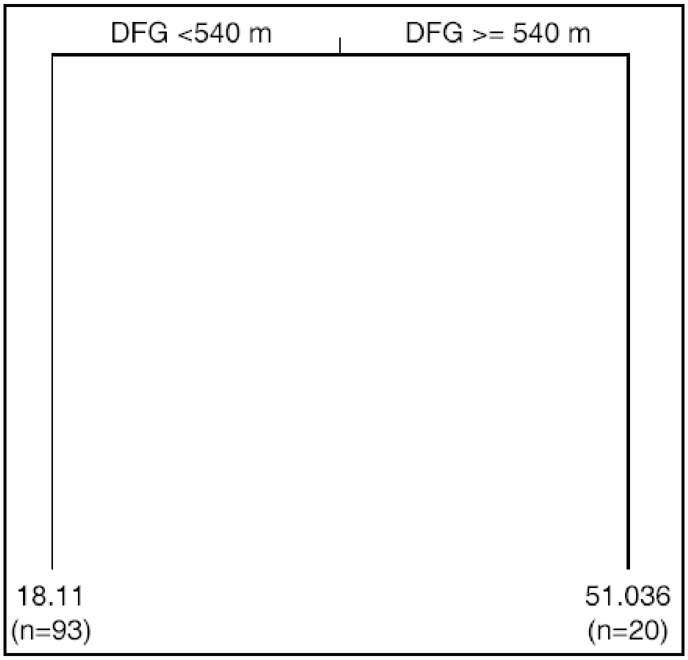

Figure 4.11. Regression tree relating vegetation cover (explanatory variable) to species richness, DFG and elevation (potential explanatory variables). The pruned tree with only DFG as the important explanatory variable explains 17.2% of the variation in cover.

Shannon Index was explained only by species richness when all the four potential explanatory variables (species richness, vegetation cover, distance from glacier and elevation) were included in the model (Figure 4.12). Though species richness alone explains 80% of variance, Shannon Index is a function of species richness; therefore species richness was dropped from the model. This reduced model identifies only vegetation cover as important predictor of the index explaining 41% variance.

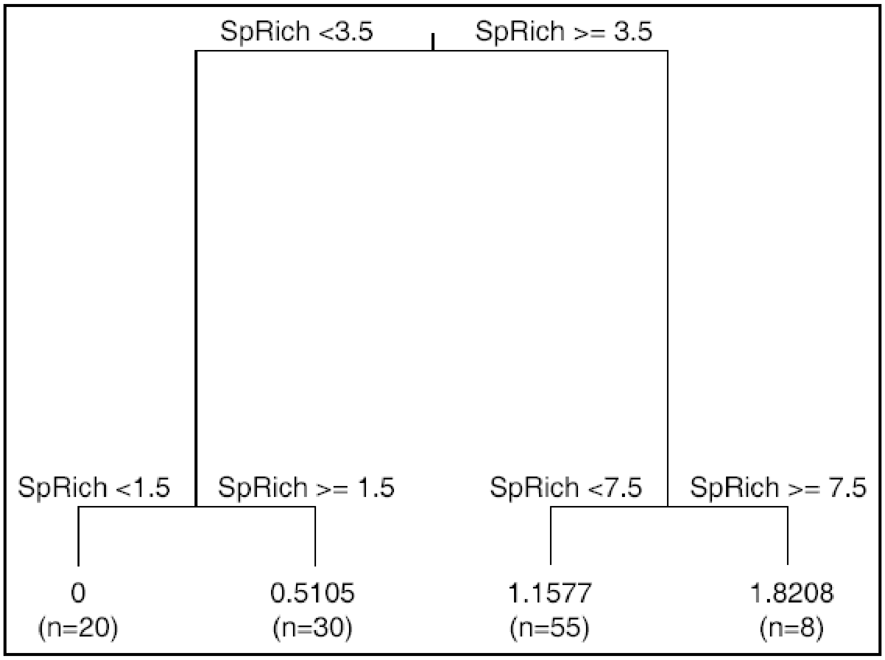

Figure 4.12. Regression tree relating Shannon Index (explanatory variable) to species richness (SpRich), vegetation cover, DFG and elevation (potential explanatory variables). The pruned tree with only species richness explains 79.9% of the variation in Shannon Index. When species richness was removed from the model, only vegetation cover is an important predictor of Shannon Index, explaining 41.2% variance.

NMDS Global

The 3 axes from the 3-D solution of the NMDS ordination provided a stress of 17.346. Stress values lower than 20 are useful to produce meaningful interpretations (Jurasinski and Kreyling 2007; Clarke 1993). The after-the-fact analysis showed that the three-dimensional solution accounted for 76% (axis 1= 39%, axis 2= 18%, and axis 3= 19%) of the species composition variation on the study area (See coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space in Table 4.3).

Table 4.3. Coefficients of Determination (r_2) for the correlations between ordination distances and distances in the original n-dimensional space.

	R Squared	
Axis	**Increment**	**Cumulative**
1	0.394	0.394
2	0.179	0.574
3	0.194	0.768

Ordination axes 2 and 3 are correlated with distance to glacier (-0.356 and -0.399 respectively) and significant (p=0.001 and 0.0001 respectively). This result is consistent with the finding of the regression analysis and reinforces the importance of distance to glacier and other environmental variables in understanding vegetation changes patterns in high mountains.

The correlation of the axis 3 with elevation is 0.244 and significant (p=0.009) whereas there were not significant relationships between elevation and the other two axes. Figures 4.13 through 4.15 present the 3 axes and five altitude categories.

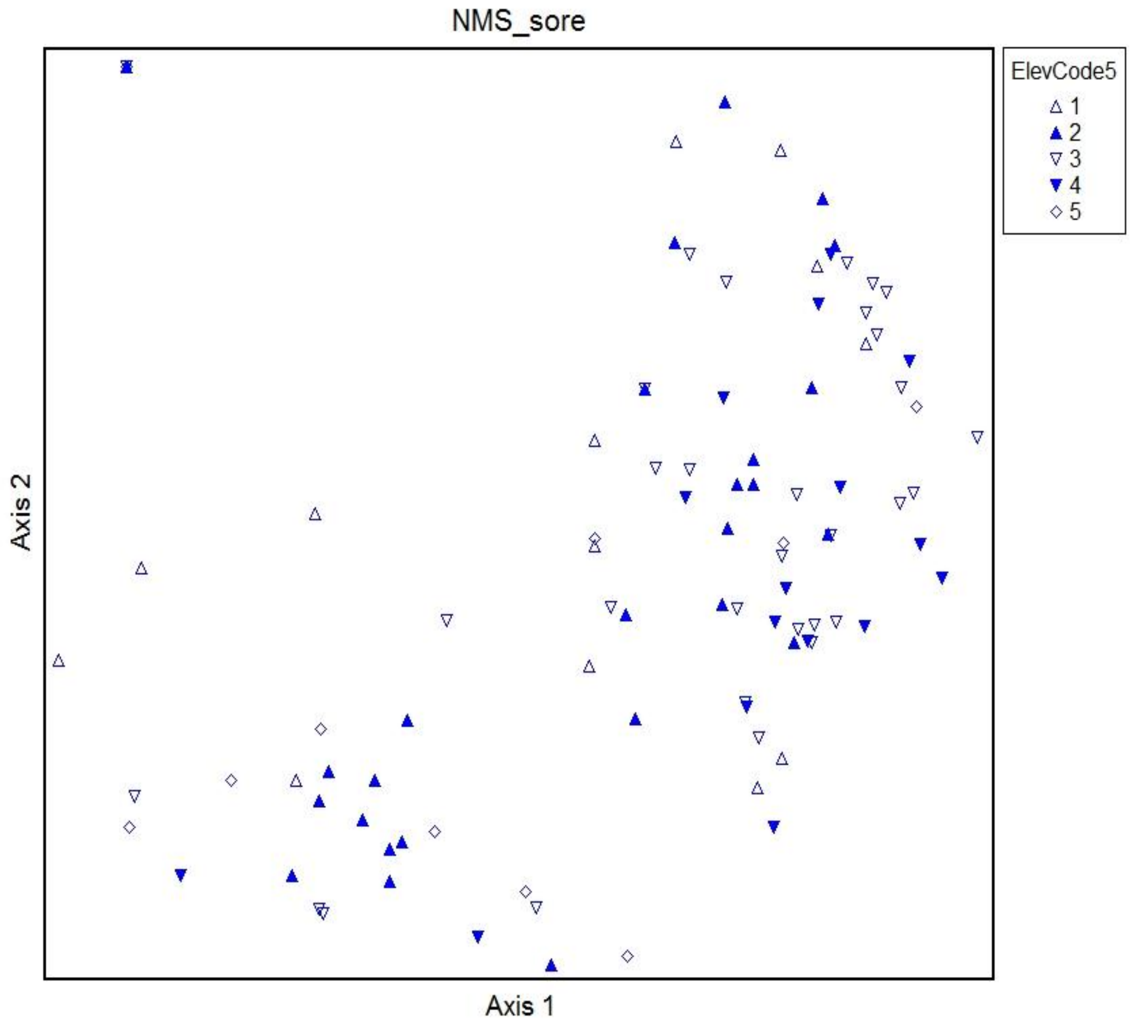

Figure 4.13. Ordination in axes 1 and 2 per elevation categories (4830 < 1 < 4900; 4900 < 2 < 4950; 4950 < 3 < 5000; 5000 < 4 < 5050; 5050 < 5 < 5113.

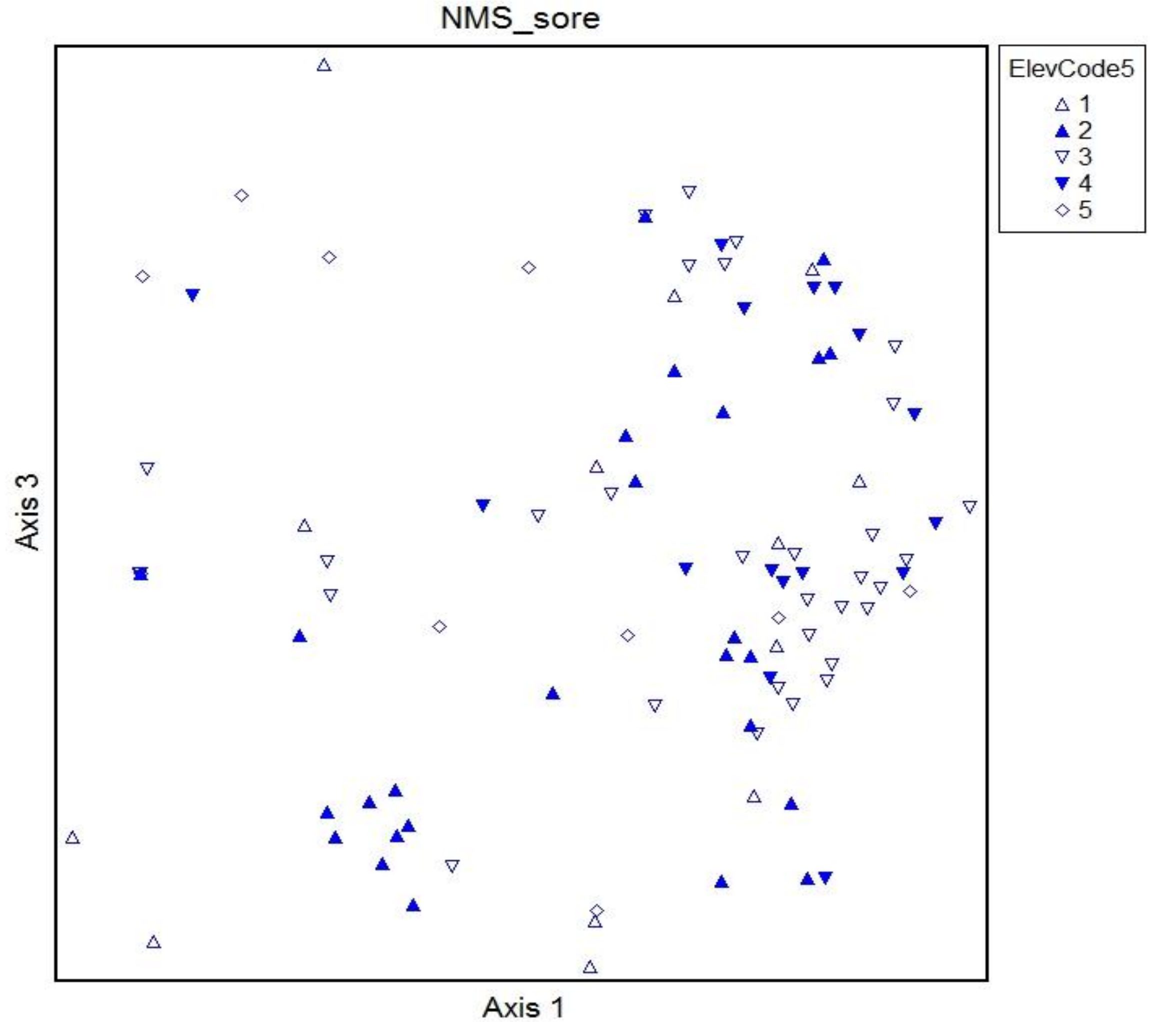

Figure 4.14. Ordination in axes 1 and 3 per elevation categories (4830 < 1 < 4900; 4900 < 2 < 4950; 4950 < 3 < 5000; 5000 < 4 < 5050; 5050 < 5 < 5113.

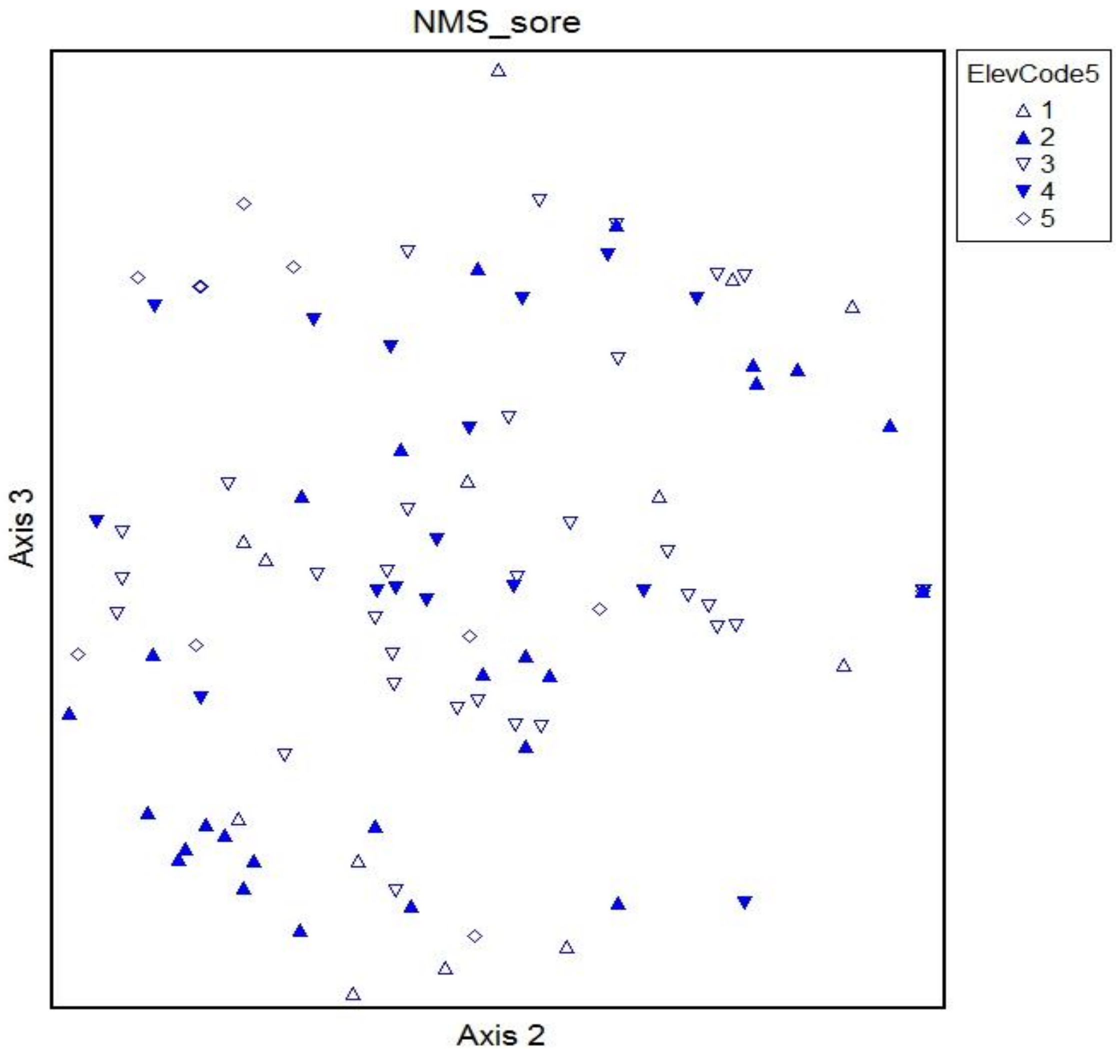

Figure 4.15. Ordination in axes 2 and 3 per elevation categories (4830 < 1 < 4900; 4900 < 2 < 4950; 4950 < 3 < 5000; 5000 < 4 < 5050; 5050 < 5 < 5113.

Species that are most strongly associated (-0.3 > r > 0.3) with the first NMDS axis are presented in Table 4.4.

Table 4.4. Species most strongly associated with first axis of NMDS.

Specie	**r**
Calamagrostis densiflora	0.791
Belloa sp.	0.575
Baccharis caespitosa	0.416
Bougueria nubicola	0.401
Nototriche sulphurea	0.35
Valeriana nivalis	0.348
Distichia muscoides	-0.342
Calamagrostis ovata	-0.392

Heterogeneity

At the study area level, using all possible pair of quadrats, the vegetation composition is very heterogeneous. The mean of dissimilarity for all the quadrat-to-quadrat comparisons was 0.8122, and the variance of the difference between the mean and each quadrat-to-quadrat dissimilarity was 0.0517.

The vegetation of the outlets is more homogeneous than within each outlet and within each transect. The mean of dissimilarity amongst the vegetation composition of glacier outlets is 0.4384 and the variance is 0.0138.

The mean of the dissimilarity between all possible pairs of transects is 0.4830 and the variance 0.0140. Heterogeneity in each glacier outlet and transect was measured comparing all possible pair of quadrats within the unit (i.e., outlet and transect) to assess the consistency of the dissimilarity across levels of analysis, from the study area to the transect level. The heterogeneity of the vegetation composition within each glacier outlet is high (see Table 4.5).

Table 4.5. Dissimilarity measures per glacier outlet.

Outlet	Mean	Variance
1	0.8295	0.0772
2	0.7653	0.09570
3	0.6852	0.0565
4	0.7717	0.0609

The dissimilarity of each transect is high, with means per transect ranging from 0.6032 (transect 4) to 0.8295 (transect 1) (see Table 4.6 for all dissimilarity in all transects). Hence, vegetation composition is consistently heterogeneous across transects, or in other words, when the vegetation of all possible pair of quadrats within a transect is compared. Further, this implies that vegetation is heterogeneous along two gradients: distance from glacier and elevation.

Table 4.6. Dissimilarity measures per transect.

Transect	Mean	Variance
1	0.8295	0.0772
2	0.7747	0.0878
3	0.7793	0.0947
4	0.6032	0.0650
5	0.7037	0.03974
6	0.7375	0.0770
7	0.7752	0.0594
8	0.7732	0.0620

The heterogeneity of the composition by elevation belt was high in all belts except in belt 1 (see Table 4.7). Heterogeneity by elevation belt indicates that even within a 30 m range composition was diverse. In the elevation belt 4 there are 9 species, the belt 5 has 17 species, the belt 6 has 34, and belt 7 has 30, then the amount of species diminishes, belt 8 has 21 species and 13 species in elevation belt 9.

The mean of the dissimilarities for all possible pairs of elevation belts was 0.6214, which is higher than means of dissimilarity for pairs of outlets and transects (see Table

4.8) indicating that vegetation composition along altitudinal and distance from glacier edge gradients is more heterogeneous than the composition across landscape contexts—existing in each transect and outlet. The variance of the difference of each belt‘s dissimilarity from the mean is 0.0348. The range of dissimilarities was from 0.8824 between belt 2 (5069 – 5099 m) and belt 4 (5009 – 5039 m) to a zero dissimilarity between belts 9 (4859 – 4889 m) and 10 (4829 – 4859 m).

Table 4.7. Dissimilarity measures per elevation belt.

Elevation belt	**Mean**	**Variance**	**Number of species**
1	0.25	0.075	3
2	0.73	0.1864	7
3	0.7586	0.0572	13
4	0.5570	0.0585	9
5	0.6549	0.0698	17
6	0.7899	0.0510	34
7	0.7948	0.0482	30
8	0.8543	0.0616	21
9	0.9444	0.0185	13
10	0.7556	0.0357	13

There is a trend of homogenization amongst outlets. Though heterogeneity is high at the study area level, it decreases when vegetation composition of each outlet is compared. This trend might pose difficulties to establish multiple trajectories of ecological succession.

There is also a trend of decreasing heterogeneity when outlets and transects are compared amongst themselves. When quadrats' vegetation is aggregated to assess the heterogeneity comparing pairs of outlets and transects, the dissimilarity diminishes substantially compared with the dissimilarity within each unit, which was calculated comparing all possible quadrats in the unit (see Table 4.8). This is explained by the fact that each pair of compared units is more similar because when the quadrats were put all together to form a unit of analysis—i.e., transect and outlet— the number of species present in the resultant unit is larger because is capturing all the vegetation present in each of the quadrats of the unit, increasing the likelihood of similarity to another unit of analysis. For instance, the dissimilarity of all the possible pairs of outlet glaciers diminishes considerably.

Table 4.8. Dissimilarity at the unit of analysis level.

Unit of Analysis	Mean	Variance
All quadrats	0.8122	0.0517
Transects	0.4830	0.0140
Outlets	0.4384	0.0138
Elevation belts	0.6214	0.0348

Vegetation composition becomes more homogenous when it was group and scale up the unit of analysis. For instance, vegetation is more homogeneous amongst outlets than within outlets, pattern followed at the transect level. Further, at the transect level the vegetation is more homogeneous than at all quadrats level but less homogeneous than at the outlet level. Although species richness increases as the time pass—or as the elevation diminishes—and species are moving their upper limits upwards, these changes do not led to different species composition in each outlet, bolstering the homogeneous significance of elevation and distance from glacier across outlets' landscape contexts.

DISCUSSION

It has been argued that diversity of alpine plants has an inverse relationship with altitude (Körner 2003) and that this reduction of species richness occurs in steps, rather than gradually, with stable amounts, for example over 200 to 400 m of altitude for the eastern central Alps (Grabherr et al. 1995). Further, this wave-like reduction of species richness reflects the "zonation of alpine vegetation" (Körner 2003, p. 15:15). Glacier retreat encourages a shift in species range to higher elevations (Seimon et al. 2007; Barry

2006; Price 2004; Pauli, Gottfried, and Grabherr 2001; Barry and Seimon 2000; Parmesan 1996; Grabherr et al. 1995). Further, in recently deglaciated high-Andean soils, it has been shown that there is an abundant and diverse cyanobacteria community in 0-4 year old bare soil, and that nitrogen-fixation rates in the 4-year old sites are two orders of magnitude higher than in the 0-1 year-old sites. Hence, heterotrophic organisms are important in pre-plant succession processes through biogeochemical interactions in newly ice-free soils, as was shown for Glacier Bay (Lawrence 1979; Worley 1973; Lawrence et al. 1967) and, later for the Andes (Schmidt et al. 2008; Nemergut et al. 2007).

Climate scenarios foresee changes that will reinforce the vegetation composition and species movement trends observed here. This reinforcement may lead to alterations in the biodiversity of high mountain ecosystems, including both new species and species extinctions (Walther, Beißner, and Burga 2005). Tracing extinctions requires long-term, systematic and comparative research from diverse and representative study sites. Further, analyze and understand interactions amongst species, and between environment and species will require experimental designs and research sites in representative high-mountain across the Andes. By the same token, social-environmental dynamics will have to be factor to assess plants behavior, because the upward shifting of vegetation will drive grazing livestock patterns that will be molded through social institutions and in turn provide a feedback to change species patterns.

Distance from glacier and elevation

Distance from the glacier lower edge and elevation are statistically significant predictors of species richness in the regression tree analysis. The biological interpretation of the significance might be complex. Though distance from glacier is the most important predictor of species richness, the upward shift of species' upper limits is not controlled by factors that are limited by distance, e.g., propagule dispersal. Further, distance from glacier and elevation inversely related, while one increase the other diminishes and vice versa. Thus, distance from glacier—as the most important predictor of species richness—can result from a combination of biological factors that are constraint by physical distance (e.g., propagule dispersal) and physical factors that depend on elevation (e.g., temperature).

Distance from glacier was the most important predictor of vegetation cover, and elevation plays a role only when the model is made more complex than its optimal. The importance of DFG indicates that ground conditions are key to understand the vegetation dispersal on uncover soil at high altitude sites. Distance to glacier has shown an explanatory power that points to the need of increase the understanding of interactions between vegetation composition and variables such as soil conditions, slope, wind, ground and underground glacier water runoff, and seeds dispersal. The secondary role of elevation explaining vegetation cover weakens its importance as limiting factor of changes in plants' distribution and reinforces the line of reasoning of the role played by other biophysical factors such as soils. The importance of elevation and its relation to temperature has been argued for research in the Alps (Jurasinski and Kreyling 2007; Rull 2004; Grabherr, Gottfried, and Pauli 2001).

Shannon Index was partially explained by vegetation cover for this study site, which in turn was explained by DFG. Thus, although elevation plays a role in the amount of species, vegetation cover is a more important factor in determining species diversity than elevation. Moreover, distance from glacier explains vegetation cover, thus influencing Shannon Index. However, results from Tibet indicate that elevation is very important regulating species composition (Shimono et al. 2010). Further, the fact that vegetation cover and distance from the glacier are better explanatory variables than elevation indicates that physiological limits of vegetation due to altitude are being overcome. Temperature changes and soil conditions altered due to glacier retreat and run off are potential factors contributing to create conditions that support vegetation cover at higher elevations. For instance, the early cyanobacterial community in recently deglaciated soils supports diverse ecosystems processes, contributes to the stabilization of soils, and fixes nitrogen, processes that will allow plant succession and soil development (Schmidt et al. 2008; Nemergut et al. 2007; Lawrence et al. 1967).

This research has found trends of increasing of vegetation cover, Shannon Index, and species richness as the distance from glacier forefront increased and the altitude diminished. The large number of species that have surpassed their former higher altitudinal limit indicates that climate change is a driver of the ongoing upward range's expansion of plants in the mountains. This is consistent with the determination of alpine ecosystems' upper limits "by low-temperature conditions" (Pauli et al. 2007, p. 147), therefore alpine plants are sensitive to warming climate (Pauli et al. 2007; Pauli, Gottfried, and Grabherr 2003; Grabherr, Gottfried, and Pauli 1994).

Heterogeneity

Species richness increased as altitude decreased and as distance from glacier edge grown, therefore if a transect is considered a unit of analysis, the inverse relation between species richness and altitude can also be interpreted as an inverse relation between α-diversity and time the substrate has been ice-free. This pattern has also been identified in the summits of the Swiss Alps (Jurasinski and Kreyling 2007). Vegetation heterogeneity amongst outlets is lower than in each outlet in this study, which can be understood as low beta-diversity in the outlet region or a homogenization as time passes—or as we move down the mountain—species richness increases, species are moving their upper limits upwards, and plant species colonize high ice-free ground. This homogenization process may be intensified both by species moving upwards and by plant selection caused by grazing pressure.

The fact that heterogeneity is higher amongst elevation belts than transects and outlets indicates the importance of distance from glacier foreland and elevation in the vegetation composition over landscape contexts in outlets and transects. Heterogeneity amongst elevation belts compares species changing at an altitudinal gradient (and distance from glacier increases as elevation diminishes), while transects and outlets—considered as whole units— compare vegetation as latitude changes. Further, the difference in heterogeneity between elevation belts and transect and outlets is consistent with the high heterogeneity found within each transect because each transect compares quadrats located at different elevation along it—i.e., transect.

The low heterogeneity in elevation belt 1 is likely due to the fact that this belt encompasses quadrats at the highest elevation range, which have no vegetation, thus they were homogeneous in lacking of vegetation. The heterogeneity of belts 2 and 3 is likely due to the fact that although there are few species at this elevation these are not the same, in fact results indicate that they only share 4 species (*Agrostis breviculmis*, *Bougueria nubicola*, *Calamagrostis*, *Senecio nutans*). The trend of increasing dissimilarity means from belt 4 to belt 9 draws from the increase in the number of species as the distance from the glacier increases and the elevation decreases (Figs. 4.4 and 4.7 and Table 4.7 for number of species per elevation belt). The dissimilarities among elevation belts might be indicating the different vegetation composition in primary—belt 1— and secondary successions—sampled belts 2 through 10— in which species' characteristics and interactions, and habitat conditions play key roles (Grime 2001; Tilman 1988).

Ecological succession

The species' location indicates not only that plants' upper limits are shifting upwards, but also that this is a dynamic group of species responding to changing conditions. These species expanding upwards overlap with species at higher elevation. The corollaries of this pattern are that the extent of the species' elevation range increases as altitude augments, and the dominance of the species with a wide altitudinal distribution over the species with a narrow one; a dominance that may lead to an increasing homogenization of the vegetation. Though species at highest elevation have the widest altitudinal distribution, there are species with narrow distributions in groups 2 and 3 of the succession (see Fig. 4.3).

The third species group is composed by species that are shifting their upper limit upward without contracting their lower limits, and a similar pattern was found in the Alps (Grabherr et al. 1995). Plants' upper limits expansion triggers questions about species interactions when overlapping. It is possible to hypothesize that groups of species at higher elevation play contradictory roles, facilitating and inhibiting the species below, while benefiting from conditions previously created by the species above. However, the species' interactions might be altered as the climate conditions change. This study has only showed that such overlapping is happening and will increase; however, an experimental design about plant functions and dynamics will be needed to test interaction hypotheses.

The assemblage of plants in the fourth species group (Fig. 4.3) does not appear to be extending their upper limit; they show a very narrow altitudinal distribution. Possible explanations for this pattern are a physiological limit imposed by temperature; unsuitable habitat at higher elevation; herbivore pressure influencing species' mobility to higher ground as was shown for mountain areas of Spain (Sanz-Elorza et al. 2003).

The bell-shape of species number along the distance from glacier foreland and altitude gradients (last column in Table 4.7) suggests that species in the mid-elevation range interact more than at the other ranges. It also indicates that in the low-elevation range the vegetation community is well established and comparatively stable while at high-elevation the community is rather dynamic and mostly formed by colonizers with the widest altitudinal distribution. Further, three processes are critical to understand succession: 1. life history traits; 2. competitive interactions; and 3. facilitation. The traits of life history establish the patterns of succession. Interactions amongst species give the mechanisms of dominance and facilitation (Chapin et al. 1994). However, out of these three processes competition may happen mostly at mid-elevation range because at high-elevation plants are sparse whereas at low-elevation the community is well established.

Chapter 5: Responses of the Quelcaya social-ecological system (SES) to social and environmental changes

INTRODUCTION

Different aspects of the past actively constitute (and are manifested in) core elements of the present day life of human groups; the pastoralists of Quelcaya are not an exemption. The ancient pattern of vertical use of the Andes (Murra 1984; Brush 1982) and the strategy of diversification (Young 2009; Zimmerer 1999) are examples of peasants' responses to ecological, topographic and climatic conditions.

Herders in the high Andes have a horizontal pattern of use of the landscape through a diversification of grazing areas by season. Ideally, the pattern is to use grazing areas in drier zones during the rainy season, whereas grazing areas near water sources and glaciers are used in the drier season (Postigo, Young, and Crews 2008; Browman 1990; McCorkle 1987). Though this pattern may be called horizontal, there are altitudinal differences between grazing areas; the ones located in drier zones are usually located at lower elevation than the areas close to water sources and glaciers (McCorkle 1987).

In addition to the biophysical conditions that population have responded to, there have been socio-economic processes that have shaped the rural Andes (Young 2008; Mayer 2002). The concepts of *legacies* and *path dependence* can be used to dynamically link Quelcaya's past with the present. "Legacies are past events that have large effects on subsequent dynamics of social-ecological systems. This generates a path dependence that links current dynamics to past events and lays the foundation for future changes" (Chapin III, Folke, and Kofinas 2009, p. 14). The meaning of path dependency in this dissertation is that past events [—i.e., legacies—] and choices establish constraints and incentives that narrow future choice sets (North 2009; Kay 2005).

In this chapter I show how biophysical conditions, and exogenous legacies—socio-economic processes—have had effects that triggered responses from Quelcaya SES. These responses, which have clearly acted upon the landscapes of the high Andes and, mid and long-term socio-economic processes—i.e., mining and fiber price—may set path dependencies of sustainable responses of Quelcaya SES to environmental legacies (Fig. 5.1). The rationale is that the responses of Quelcaya's social system to other major changes—e.g., socio-economic—have (and will) limited and shaped the adaptive responses to environmental change.

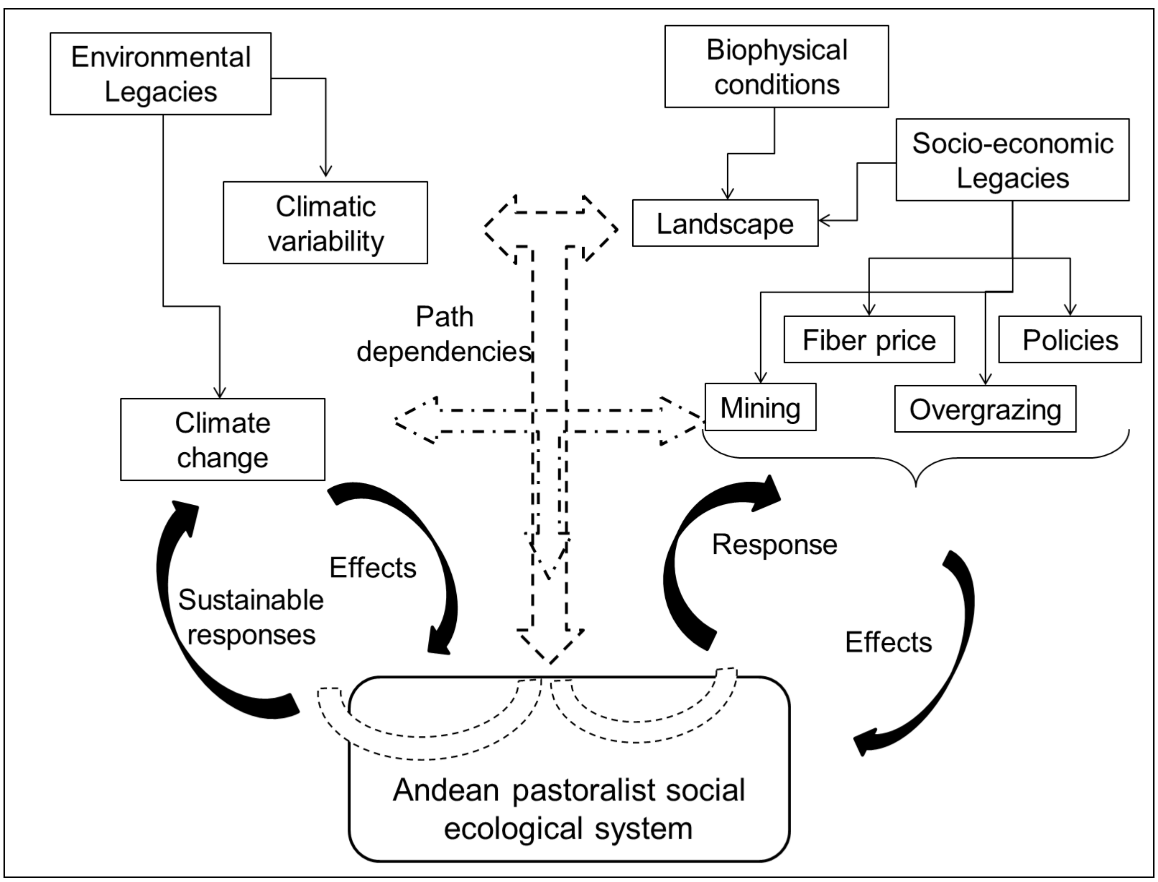

Figure 5.1. Responses to effects of biophysical conditions and socio-economic legacies (right side) generated a path dependency (dashed arrow) of sustainable responses to effects of environmental legacies (left side).

LEGACIES AND PATH DEPENDENCIES: OVER A CENTURY OF LIFE IN QUELCAYA

The oldest documented evidence of Quelcaya herders in the study area is from the 1863 *Padroncillo de Contribuyentes de la Provincia de Carabaya y Distritos* (Fondo Tesorería Fiscal 1863) (Fig. 5.2). In this provincial book of tax payer records, a group of men were registered as grazing their livestock in the current Quelcaya zones of Llapha, Pacco, Ancassi, Huisaguisa, Zapanuta, and Quelcaya itself 150 years ago (Fig. 5.3). This smidgeon of evidence sheds light on four important legacies and socio-economic processes: 1) the long-term linkage between land and herders (e.g., some of the registered men have last names that are still found among current Quelcaya families), 2) the relationship demonstrated between households and the government through tax payments, 3) the raising of livestock as the major economic activity over the last century and a half, and 4) by inference, the long-term involvement of households in market relations that grant them access to money.

These legacies and socio-economic processes have generated path dependencies that have configured part of the current Quelcaya SES. For instance, the herders-government relationship in Quelcaya has been changing with regard to the struggles of the herders for secure their land rights. In the 1860s the herders showed that they were owners by paying taxes; even nowadays some herders pay a tax to the municipal authority because they believe that the payment receipt proves ownership of the land. During the 20th century the relationship between government and herders was characterized by herders' defense of their lands through years of social strife and legal suits. These struggles took place in court against *hacendados* (landowners of large estates) or on the land, against *hacienda* (large estate worked by tenant labor) managers who disregarded pastureland boundaries and invaded the property of the herders. The herders not only maintained a defensive posture, however, because they also took advantage and expanded their land. For instance, the land where the village of Quelcaya is located has not always been part of the community; it used to be part of the Hacienda Carmen. However, after the 1969 Agrarian Reform the herders took part of Carmen's land knowing that: 1) the property of the hacienda changed from relatives of the landowner to his former administrators; and 2) the new owners were absent from the estate. In the absence of the owners, the herders occupied the main house.

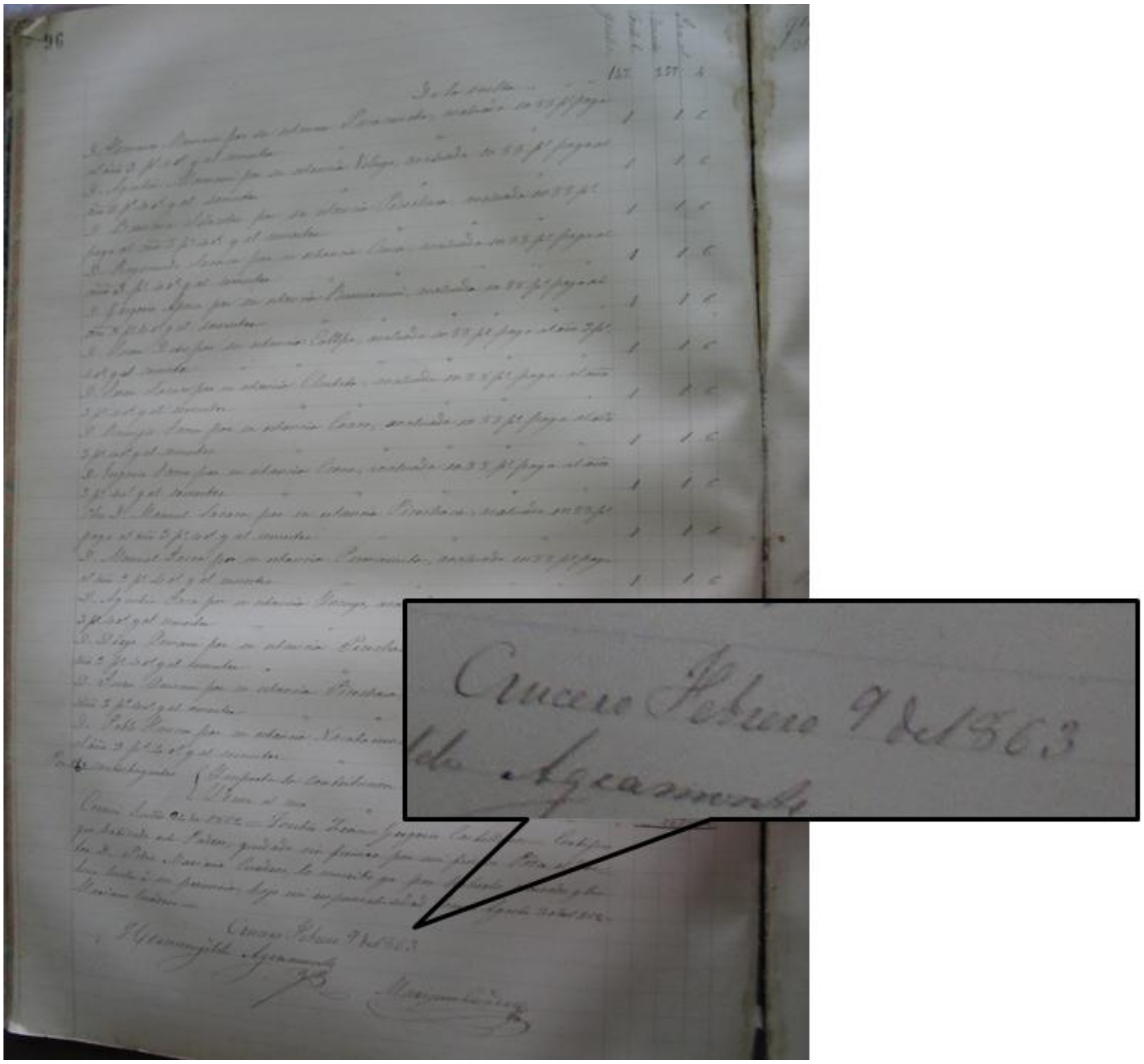

Figure 5.2. Page of the document *Padroncillo de Contribuyentes de la Provincia de Carabaya y Distritos* (Fondo Tesorería Fiscal 1863) stating the date it was issued. The zoom in callout states that it was signed in Crucero on February 9th of 1863 ("Crucero Febrero 9 del 1863")

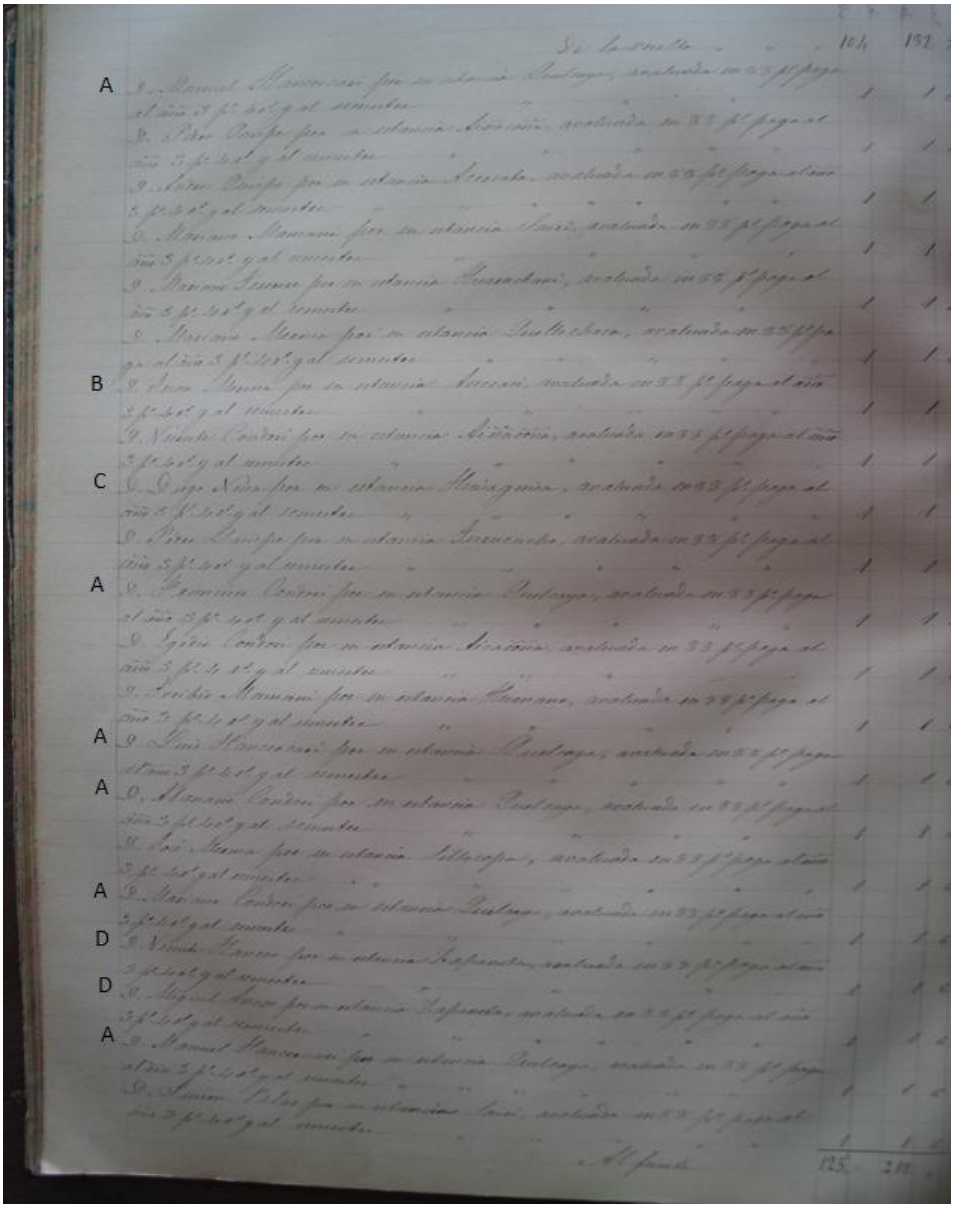

Figure 5.3. One the pages of the 1863 document *Padroncillo de Contribuyentes de la Provincia de Carabaya y Distritos* (Fondo Tesorería Fiscal 1863) stating the names of the tax payers and the location of their pastureland (A in Quelcaya, B in Anccasi , C in Huisahuisa, D in Zapanuta)

The agrarian reform of 1969 (AR) in Peru was an event that set a path dependency of empowered peasants, whereas the rural aristocracy was dispossessed of their material power and property (Eguren 2006; Hunefeldt 2004; Caballero 1981). Up to 1979, 30.3 % (9.1 million of hectares) of the arable land was expropriated and redistributed to 369,000 families (Contreras and Cueto 2007). The AR finished the rule of landowners in rural areas and ended the oligarchic regime (Contreras and Cueto 2007; Hunefeldt 2004; Yepes 1992; Bourricaud 1966). In so doing, the AR brought to an end the figure of the landowner (*hacendado*) who was a respected, feared and powerful figure in the region; this figure represented also law and order in the rural areas. Further, the political environment characterized by 'pro-peasant' and 'the land belongs to who works it' in the early 1970s, granted legitimacy to the actions of the herders whereas it discouraged any retaliatory action by the former hacienda owners.

In addition to the political changes, the Agrarian Court System was created to administer justice in all land matters but expropriation. Land expropriation was decided by the state and could not be questioned (Cleaves 1980). In this context, Quelcaya's herders felt a more secure tenure over the pasturelands because landowners of the Hacienda Carmen left the estate, and there were no more attempts to take the herders' land. This context was quite different before the AR. There is archival documentation, from prior to the AR, stored in the Regional Archive of Puno, showing complaints of the Quelcaya herders to local and national authorities against *hacendados* and urban-based citizens who invaded part of their lands. For instance, several letters from herders from Quelcaya, dated between 1922 and 1927, complaining against the landowner Felix Riquelme who took over pastures and livestock that belong to the herders. Another example is the letter from Manuel Hancco (5/10/1922) to the Section of Indigenous Issues of the Ministry of Public Works. In this letter Hancco reported that Riquelme unlawfully appropriated the land of Zapanuta area in Quelcaya. The landowners and urban-based citizens claimed property of pastures with fake titles; further, there were others that wanted land granted by the government as compensation by services they did not provide.

In the 1980s the relations between herders and government shifted direction when the Quelcaya herders tried to benefit from a new government policy to redistribute land. The policy aimed to distribute land among communities, thus Quelcaya herders formed a legally recognized community in 1988. Though the herders did not receive any land from the redistribution policy, the creation of the community secured the land with a formal community title.

The raising of livestock has been the main economic activity in Quelcaya, which can be seen as a result of the interactions among biophysical factors, climatic conditions, and herders. These interactions generated a path dependent herding, in other words, the different conditions of Quelcaya constrained the possible activities to herding. The men registered in 1863 (Fig. 5.3) were paying taxes for grazing, and in three cases extended families (different members of the same family registered in the document of fig. 5.3) controlled large areas which gave access to different grazing areas. To control and access different areas shows the seasonal character of livestock keeping; a character that was still found to be present amongst the households during the fieldwork for this dissertation in 2009. Further, the seasonality points toward the mobile nature of herding. In Quelcaya, this mobile nature is embedded in current livestock keeping, acknowledged as crucial to respond to harsh environmental conditions and to extreme weather events, such as drought. For instance, a quote from a herder, responding to a question in a semi-structured interview, will illustrate this important characteristic: "¿Qué hace cuando hay sequía? (…) les llevo a los animales a otra zona donde hay pasto pues, les traslado a los bofedales con agua" (What do you do when there is a drought? (…) I take the animals to another zone, wherein there obviously is forage, I move them [the livestock] to the wetlands that have water).

Though there is agriculture of bitter potatoes in the lowest parts of Llapha sector, it was only recently introduced into the community. There is no evidence that crops were planted in Quelcaya previous to early 1980s. The herders recall the story of the "discovery" of agriculture in Quelcaya as follows: At some point in the 1980s a herder asked an agriculturalist who he bartered with, in a valley of Cusco, "how do you make the land produce crops" ("¿cómo haces para que la tierra de cultivos?"). The agriculturalist not only explained the different activities that the cultivation of crops entail but gave the herder some seeds of potatoes to sow on his own land. The first attempt of the herder failed, but with more advice from his agriculturalist friend, and more care from the herder in the cultivation process, potatoes began to grow in the warm part of a formerly glaciated valley (Fig. 5.4). After having several successful harvests of bitter potatoes, the herder also sowed fava bean, barley, and other tubers, only to face failure again. Thus, only bitter potatoes have succeeded in the harsh environmental conditions of Quelcaya, as of the time of this fieldwork. Later, the sons of the herder who "discovered" agriculture donated the agricultural land to the community so anybody could cultivate. Yet, not everybody does so because some herders found that the agriculture's zone is far from their house so the distance traveled and the time spent—amongst other expenses—are not compensated by the output. Furthermore, the lack of an agricultural tradition and of planting field crops impose an extra cost in terms of learning process and errors. Thus, this adaptation of the society and the adoption of a crop have not been adopted universally or equally by all the households; approximately 20 families out 110 farm in Llapha. Instead it has been incorporated as a possibility within the whole set of household possible activities, which are assessed each season to finally decide whether or not undertake such an endeavor.

Figure 5.4. Potato field in the glacier valley of Llapha sector of Quelcaya.

Tax payment was done with money, which can only be obtained by selling a commodity. Thus it can be inferred that herders in Quelcaya had access to money, at least back in 1863, in order to pay their grazing tax. Whether the money came from selling fiber or from a paid job, to have money implied that herders were not isolated or formed a closed group more than 150 years ago. Instead it is likely that they sold fiber to a landowner or middlemen (for the wool market in the Peruvian southern Andes see: Burga and Reátegui 1981; Orlove 1977). Further, it may be possible that the herders had some wage off-farm labor, though, it is less likely considering that *hacienda* tenants were the most common suppliers of labor force. Currently selling alpaca fiber to the intermediaries is still the steadiest source of money to Quelcaya herders; however, herders have diversified their money sources with seasonal off-farm wage labor, mostly in construction or for the mining company.

Isolation has diminished in Quelcaya in the past five years according to my informants. The increasing presence of the “outside world” is expressed through infrastructure (electric power and potable water) and mining companies. Based on interviews in 2008, the community perceives these changes as an improvement in their living conditions and as an opportunity to obtain some benefits including money. Between my first visit in 2007 and the most recent in 2010, the number of little convenience stores in the village of Quelcaya has increased from two to five, indicating an increased level of availability of consumer goods. Likewise, the number of stereos, TV, and DVD players has multiplied, and with them the noise in the village has increased.

The long-term relationships of Quelcaya herders with both the land and government; the raising of livestock; and the involvement of households in market relations are the legacies that constitute sources of path dependencies. Though these paths are intertwined, forming a thread that has supported the community and the households, some of these legacies and their paths have also been source of change for the SES (Fig. 7.1 in Chapter 7), as will be discussed in the next section.

THREE EXOGENOUS DRIVERS OF SOCIAL AND ENVIRONMENTAL CHANGE FOR QUELCAYA

Mining

There is one international junior mining company (Bear Creek Mining Company) carrying out exploratory activities for copper and zinc in Quelcaya at the present time. In 2006, the company established relationships with the herders and the community. These relations are both formal and informal. The former are specified through an agreement between the company and the community, which includes that the mining company: 1) pays to the community a yearly amount for an authorization to perform a set of activities on specified sites; 2) hires community members to work; 3) establishes a program of corporate social responsibility; and 4) supports and attends to community requests to the extent possible. This last point creates room for less formal benefits. Further, there is a tacit understanding that a negative response from the company will bring opposition (or lost support) and will not contribute to the company's strategy of maintaining good relations with the community.

The mining company hires a crew of seven community members each month to work as guides or in road maintenance (Fig.5.5). The crew members are chosen by the community. Though the herders carried out wage labor as temporary employees of the company, this is not a traditional worker/firm relationship. The community and the company agreed on the number of workers to be employed; then the community makes a roster of members that want to work and establishes an order to take monthly turns. Each monthly crew has a responsible head who keeps track of attendance, receives the work instructions, and monitors the workers' performance. If there is a complaint from the mining company, it is taken to the communal authorities; likewise these authorities will relay the complaints of the workers to the mining company. In so doing, the community

Figure 5.5. Crew working on road maintenance.

function is twofold: 1) it acts as might a union, protecting the community workers from the employer—i.e., the mining company, and 2) it guarantees that the hired herders fulfill their job obligations. Furthermore, other relations, stipulated in an agreement between the community and the mining company, are deployed. Any incompliance for the company is sanctioned by the community. For instance, in a pre-fieldwork visit to Quelcaya carried out in 2007, I was told that a mining company was served with a fine of US $ 10,000, which it was paid, because three trucks went to zones that were not included in the agreement.

The program of corporate social responsibility includes the provision of social services like: medical and dental campaigns in site (community) and tests for pregnant women in a public hospital in Juliaca; a project to improve livestock husbandry through technical assistance; a program of scholarships to pursue high school education in the province capital; transportation of patients in emergency cases; and the support of communal activities like fairs and anniversaries. There are also unplanned requests of the community, which are sorted out by the mining company as they arise on a daily basis. The most common unplanned requests are for transportation of community members in the company vehicles, and the donation of money or materials to build infrastructure.

The mining-community relationship also includes disadvantages. Quelcaya's population is well aware of the threat that mining activities pose to natural resources, especially to water quality in rivers and lakes. This threat has two major components: first, pollution of the water derived from the mining activities, and second, lost access and control over the water bodies. Pollution and demands from mining activities have revived inter-generational tensions as well as between families and the community in the last three years. Families whose land will be directly affected by mining activities think that the community arrangement is a disadvantage for them, because any money from the mining companies is received by the community as a whole. The community, in turn only gives a small share of the received money to the directly affected families, whereas the rest is spent on communal expenses; I call this the "tragedy of the privates". These families do not acknowledge or recognize that mining company-community relations are more fair and equitable because the community is negotiating with the company rather than with each family individually. Directly affected families believe that they would be better off carrying out direct and individual (family-company) negotiations; these families neglect the uneven nature of the power relations, and of the education and knowledge between herders' families and mining companies.

Further, I would argue that mining represents a large threat to pastoralism because of the potential pollution of water, pasture and soil. Additionally, climate change has dramatically increased prospecting by mines in high latitude because the shortened duration and extent of sea-ice cover (Prowse et al. 2009; Vieites, Min, and Wake 2007; US Department of Interior 1961) This menace increases due to the lack of a proper institutional framework or even capacity to monitor mining activities in the study region. Furthermore, lack of an institutional framework worsens when relations between the community and the company are uneven, where the company has the power, knowledge, and capital. A less direct threat is posed by the sustained inflow of cash due to wage labor by the same households. First, it may deprive the poor families of labor force needed for herding. Second, a constant monetary income for some households, whereas some families do not have members working for the mine, may engender social differentiation within the community. So far, the roster and the system of turns have been an efficient mechanism to distribute the opportunities and the wage labor among the commoners.

Mining is not a recent activity in the province. The mineral resources of the province were already acknowledged in the 19th century (The New York Times 1889; Markham 1873). During the fieldwork carried out in 2008 there were three mining companies conducting exploratory work; however, two of them ceased operations in

2009 due to the financial crisis. Although they said that this was a temporary shut down and that they will be back shortly, they had not come back as of the end of 2010.

The alpaca fiber

Alpaca fiber is the main source of monetary income in the household economies of Quelcaya, thereby conversations about fiber price are constant as I witnessed during the 2008-2009 fieldwork. Though they shear the alpaca fiber, ideally, once a year between December and January, they may sell fiber or animals at other times if the need for cash arises. Based on interviews with Quelcaya herders, the bulk of the fiber is sold to intermediaries in Macusani, the capital of Carabaya province, which requires a five hour trip (one way). However, the herders also said that they may sell small amounts of fiber in the community to any of the two traders who go to the community for the weekly fair on Sunday (Fig. 5.6). Whether sold in the community or in Macusani, the price of the fiber is always fixed by the buyers who also receive a fixed price from larger buyers, and these larger buyers in turn also have a fixed price set by the textile manufacturers in Arequipa (Matute, Holgado, and Vásquez 2009). At the top of the fiber commodity chain is the international textile industry (Matute, Holgado, and Vásquez 2009; Burga and Reátegui 1981; Orlove 1977).

The sale of fiber from Quelcaya herds is a transaction with three salient characteristics. First, herders sell alpaca fleece by weight. Second, the white fiber is more in demand by the textile industry, which is driven by fashion and customer preferences. Third, there are no price incentives for quality because the intermediaries pay a flat price regardless of quality. These conditions shape a herd management that aims to increase fleece weight and to “whiten” the herd. Another element shaping the herd is that herders understand livestock as assets. Hence the larger the herd, the more assets the household

Figure 5.6. Alpaca fiber sold in Quelcaya Sunday fair.

has. Thus, herders enlarge the herd size by keeping the animals until very advanced ages, which in turn increases the amount of fleece produced by herd. It has been shown that fleece weight increases with age due to enlarge body size, while fiber diameter significantly thickens until the alpaca is six years old[2] (León-Velarde and Guerrero 2001). Another reason to keep aging animals is the provision of dung (McCorkle 1987; Winterhalder, Larsen, and Thomas 1974).

Further, keeping old livestock also levels off the selection pressure from low births and high mortality rates of alpacas (Wheeler 1995; Garmendia et al. 1987). However, maintaining old livestock prevents the selection process carried out by culling old animals, as was shown by León-Velarde and Guerrero (2001) in the Peruvian Altiplano. Consequently, keeping old livestock increases the level of consanguinity, which may be diminished by exchanging sirens amongst herds (León-Velarde and Guerrero 2001). In the case of Quelcaya, most (57%) of interviewees stated that their herds have had the same size over time because birth rates and the limited culling of alpacas had been matched by the mortality rate caused by harsh climate. Furthermore, the majority of the herders are not interested in carrying out the activities of animal selection or livestock management to improve the quality of the fiber. The reason for the lack of interest is that there is no stimulus to improve quality because fiber is bought by a flat price regardless of the quality.

Climate

Climate is another exogenous driver acting upon Quelcaya. The data collected from the Peruvian National Service of Meteorology and Hydrology (SENAMHI) in 2009 is consistent with the perceptions of community's population (see subsection "Herders

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[2] Alpacas have a life span of around 20 years.

and environmental change" in this chapter): more extreme temperatures (colder at night and warmer during the day) and a shorter rainy season. In this sense, the perception of raising temperature during the day is consistent with data from Macusani (capital of Carabaya province). These data show a trend of increasing Maximum temperature, within fluctuating ranges, in the summer months (JFM) of the Southern Hemisphere, since 1999 up to 2009 (Fig. 5.7). Similarly, perceptions of diminishing temperatures have some degree of consistency with data of Minimum temperatures in winter months (MJJ), which decreased sharply between 2002 and 2006 (Fig. 5.8). Further, Bradley (2009) showed that temperatures were frequently above freezing between September and May since 2004 at the summit of Quelcaya glacier. Projecting these results, it was found that daily Maximum temperature persistently was above freezing for most of the year at the glacier's margin (Bradley et al. 2009).

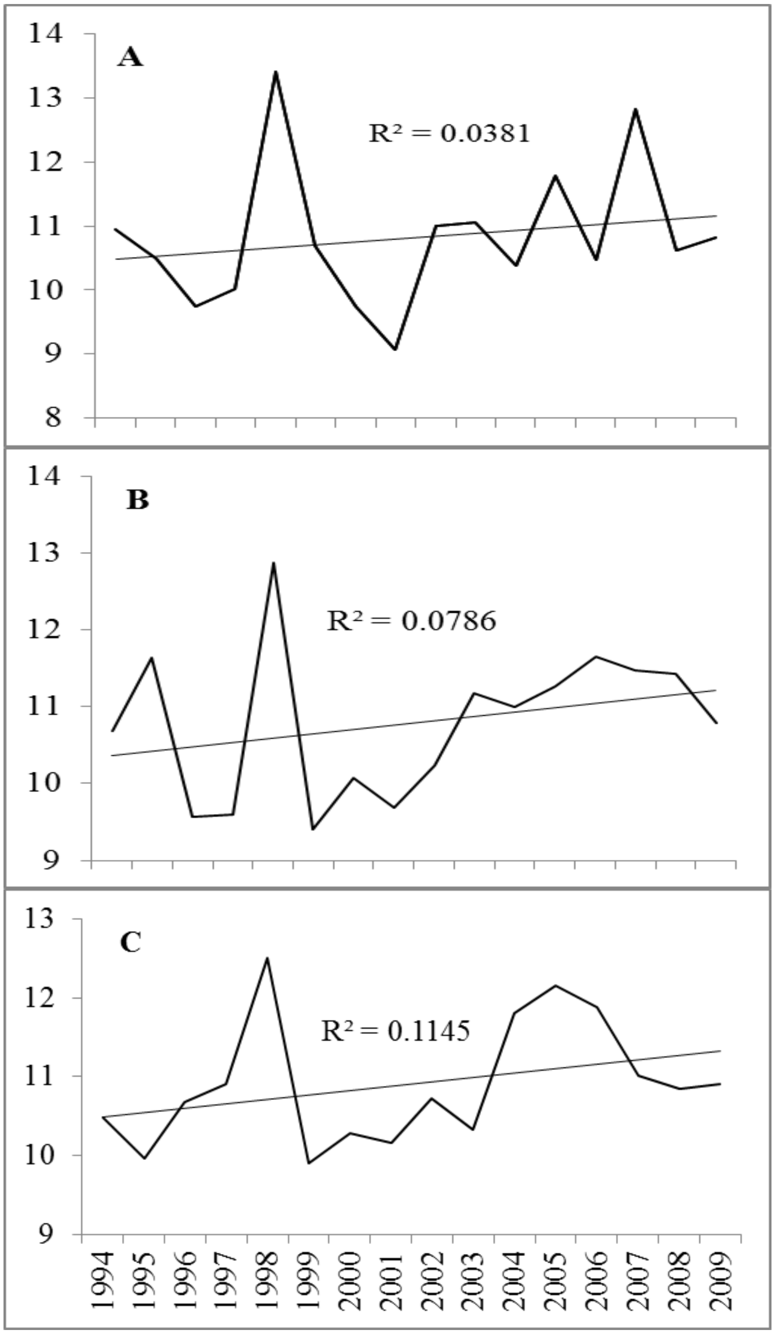


Figure 5.7. Trendline of maximum temperature (°C) in Macusani for (A) January, (B) February and (C) March from 1994 to 2009.
Source: SENAMHI

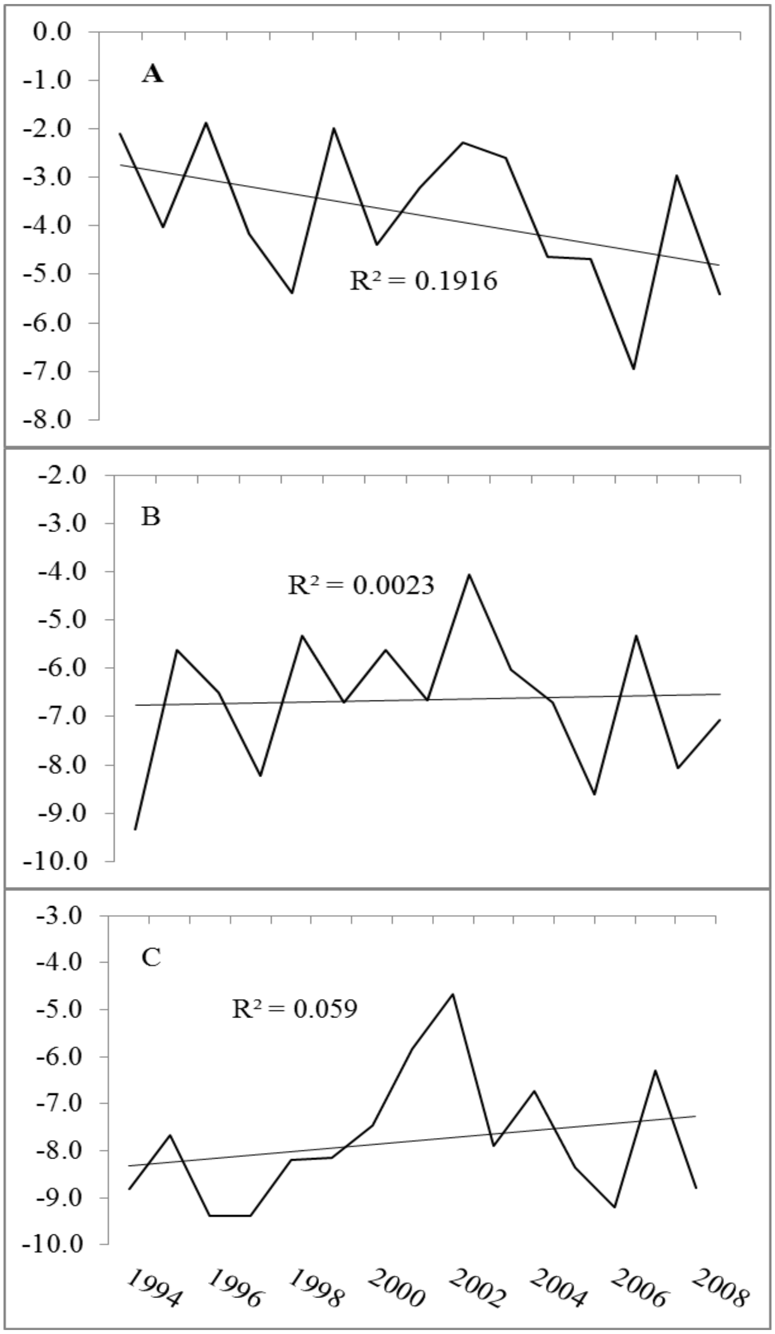


Figure 5.8. Trendline of minimum temperature (°C) in Macusani for (A) May, (B) June, and (C) July from 1994 to 2008.
Source: SENAMHI

Though the total annual precipitation has fluctuated (Fig. 5.9), the figures 5.10 and 5.11 show the trend of diminishing precipitation in the months of the onset (ASON) and the end (MA) respectively, of the rainy season between 1993 and 2008 in Macusani (Carabaya's capital). The pattern of decreasing precipitation is more noticeable in August and September, which were former months of rainy season onset. This pattern indicates that the onset of the rainy season has changed to October (Fig. 5.10 C). Furthermore, rain has diminished over time in March (Fig. 5.11 A), so as time goes on, March has become less rainy, April is holding its own and is lower.

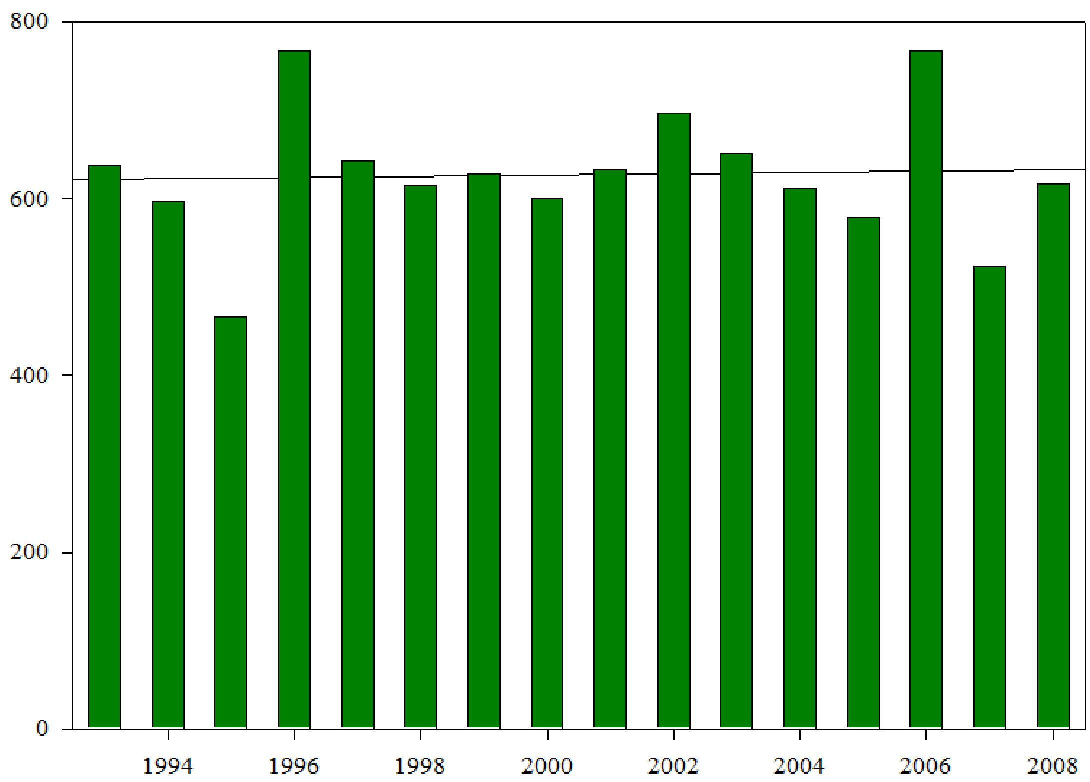


Figure 5.9. Trendline of annual precipitation (mm) in Macusani from 1993 to 2008.
Source: SENAMHI

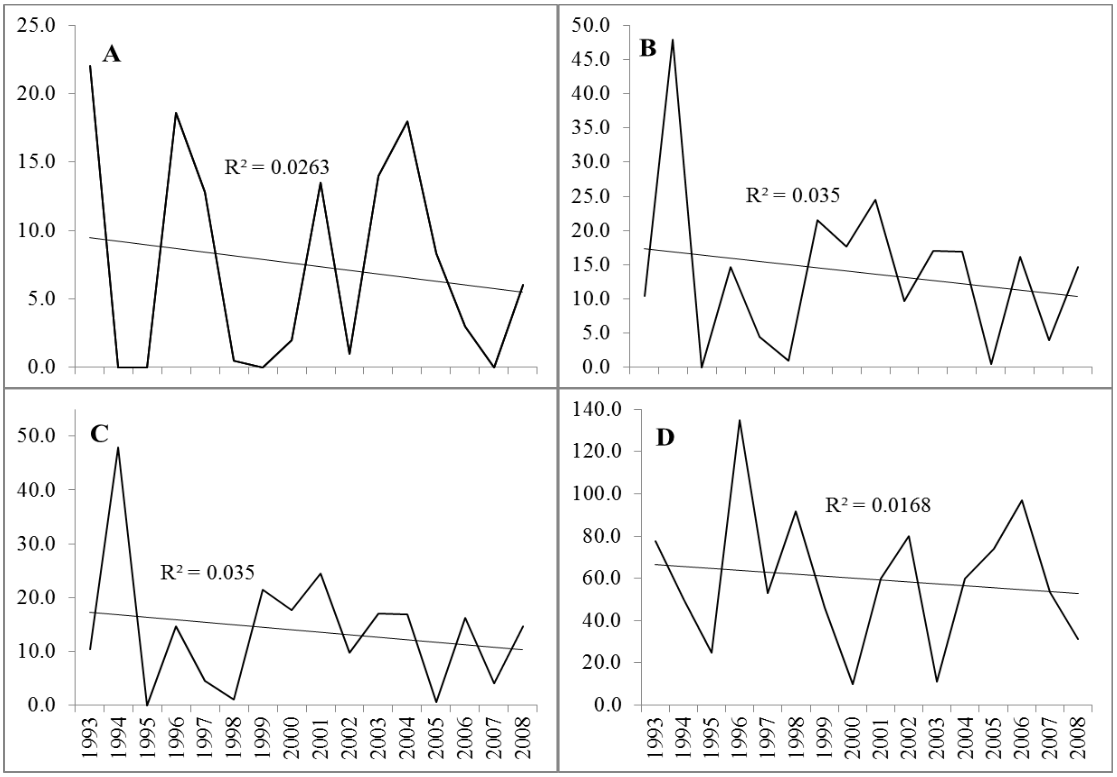
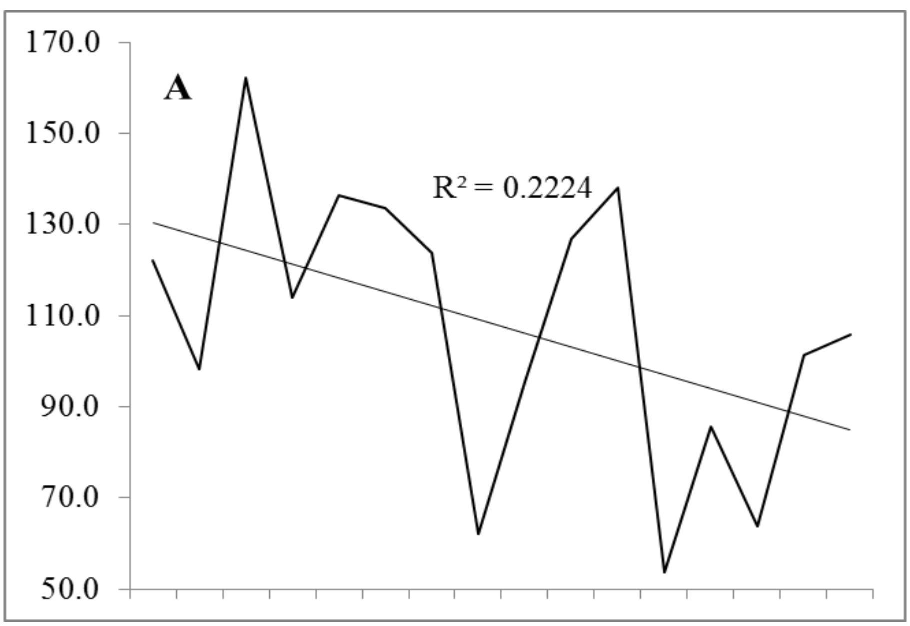


Figure 5.10. Trendline of precipitation (mm) in (A) August, (B) September, (C) October, and (D) November (ASON) between 1993 and 2008 in Macusani (Carabaya-Puno). These months encompass the onset of the rainy season.
Source: SENAMHI



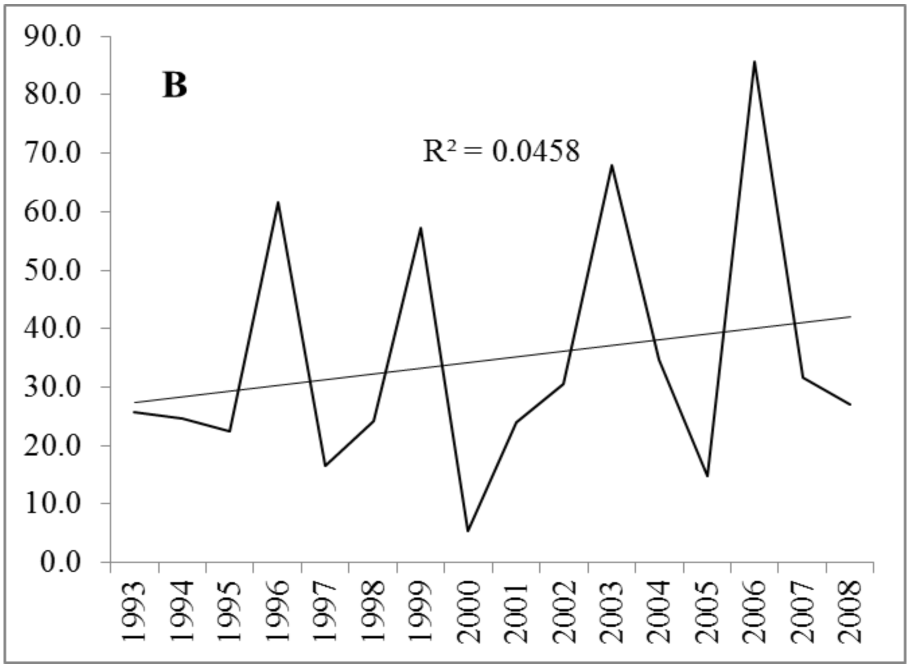


Figure 5.11. Trendline of precipitation (mm) in (A) March and (B) April (MA) between 1993 and 2008 in Macusani (Carabaya-Puno). These months encompass the end of the rainy season.
Source: SENAMHI

SOCIAL ORGANIZATION

Quelcaya's social organization has three levels: household, supra household, and community. Though all the levels are formed by households and all the households are part of the community, supra household organizations are formed by different subsets of households. Further, one supra household organization—the *ronda*—is nested within higher levels of organization that correspond to the political division of Peru—district, province, department (Fig. 5.12)

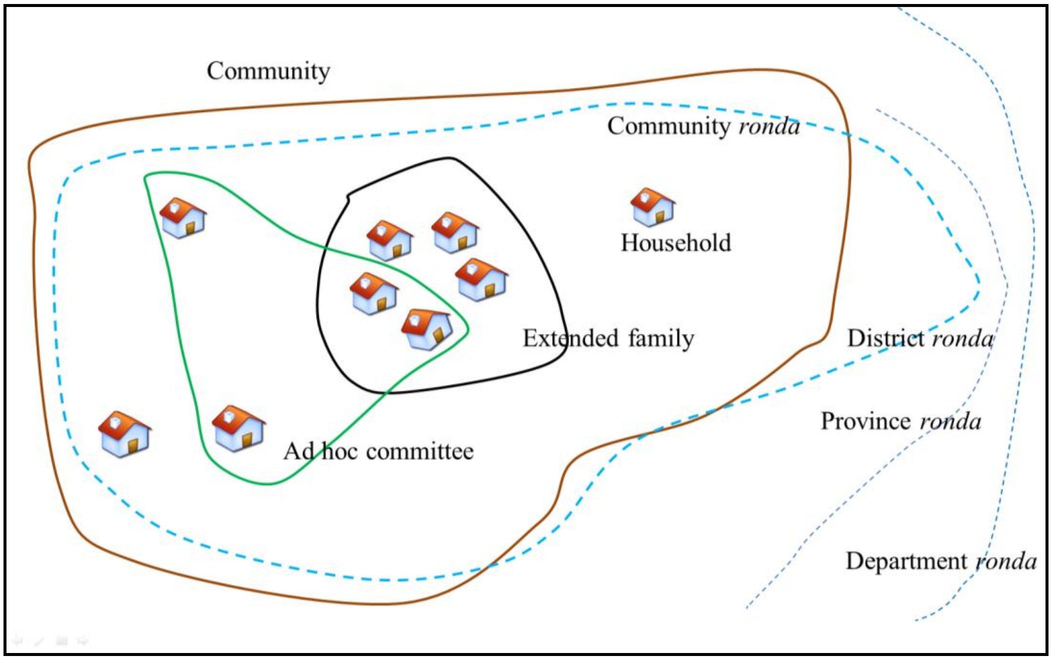


Figure 5.12. Three levels of organization in Quelcaya and the night-guard committee (*ronda)*

Households

There are 110 households in Quelcaya. At the time of the fieldwork the average number of members per family was 4.64, the median was 5 people, and the range of family size was from 1 to 10 family members. The average age of the parents in the household was 43.89 years, with a standard deviation of 15.76, the median age of the parents was 41 years, and the range was from 20 to 85 years (Table 5.1). The educational level of the households is low, which is consistent with the situation of most of the rural households in Peru. The highest education level of the parents is complete college education reached by two male parents, while 16 people have no education. Figure 5.13 shows a histogram of the number of parents per education level.

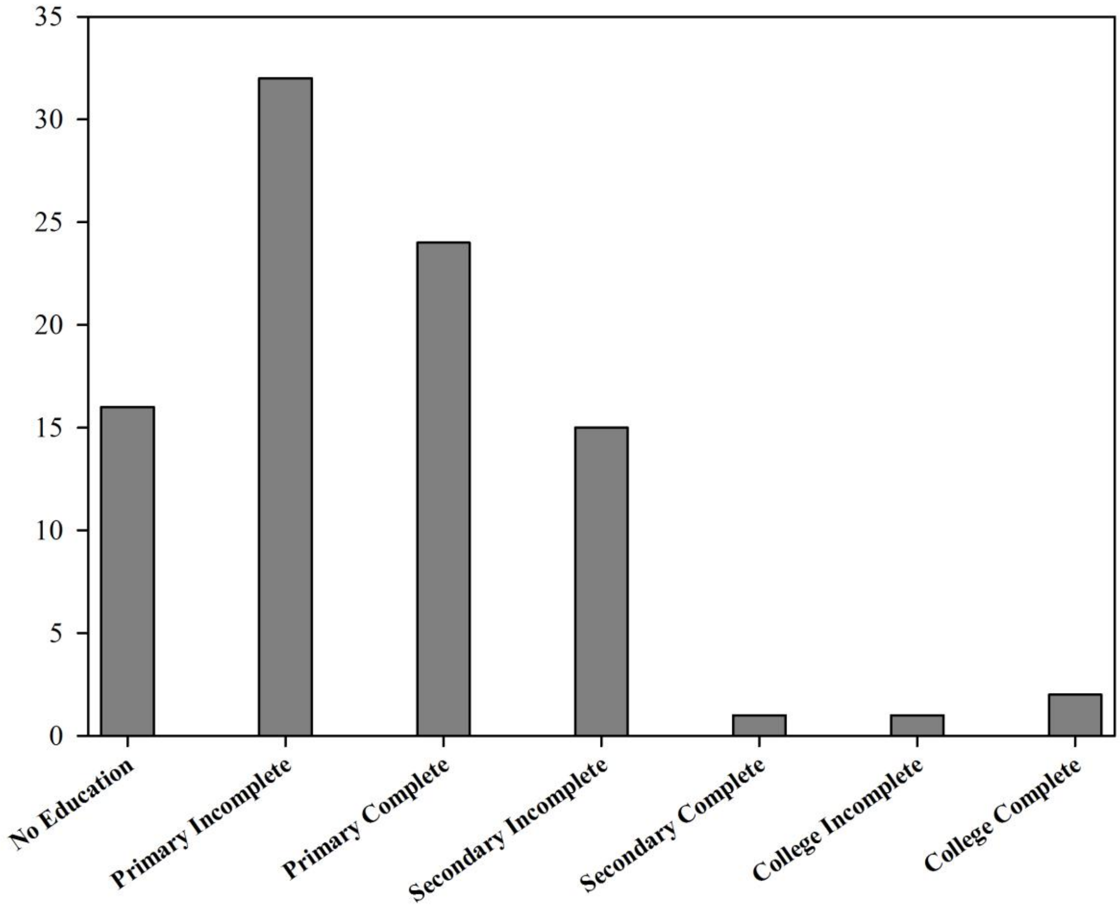


Figure 5.13. Number of parents per educational level.

Household economy

The household economy of the herders is fundamentally of subsistence. Pastoralism is the main economic activity of the households in Quelcaya. The household

Table 5.1. Household size and Age of the Couple Household Head

Number of Family Members				Age of Parents in the Household				
Average	Median	Min.	Max.	Average	St. Dev.	Median	Min.	Max.
4.64	5	1	10	43.89	15.76	41	20	85

owns the livestock and usufructs the land, which usually belongs to the extended family, although there is only one communal title. The household is the unit of production and consumption in Quelcaya, as well as in other communities in the Andes (Mayer 2002; Orlove and Custred 1980). Production is carried out by the household and/or the extended family that provide the labor force for livestock husbandry. The average size of the labor force (family members older than 6 years old) is 3.82 (1.94 male and 1.88 female), with a standard deviation of 1.88 (1.24 male and 1.15 female) (Table 5.2). The largest labor force in a household is of nine members while the smallest is of one. By gender, the minimum size of labor force is zero for both genders, while the maximum number of labor force member per gender for each household are 6 and 5 for male and female respectively (Table 5.2).

Table 5.2. Average and Standard Deviation of labor force (> 6 yr. old)

	Average	Standard Deviation	Maximum	Minimum
Community	3.82	1.88	9	1
Male	1.94	1.24	6	0
Female	1.88	1.15	5	0

Though the households of Quelcaya raise mixed herds of alpacas, llamas, and sheep, the alpaca is predominant in all the herds. Furthermore alpaca is the most prominent species since it provides fiber, hide, and meat. Llamas are used as pack animals, and they may provide meat and wool, the latter used to make pants, sacks and ropes. Sheep provide wool, hide, and meat; the wool is woven into blankets and hats, the hide is usually laid on the floor to serve as a bed. Table 5.3 presents some statistics of the herd composition as of the fieldwork in 2008–2009.

Alpaca fiber has historically been the steadiest source of money-income in the household economy of herders (for historical perspectives on the economy of alpaca fiber see: Jacobsen 1993; Burga and Reátegui 1981; Orlove 1977). The importance of fiber for the Quelcaya household is reflected through two facts that I noticed during fieldwork in 2008 and 2009: 1) the price of fiber was a constant topic of conversation amongst herders, and 2) herders were up to date, in general, with news about fiber, and more specifically, with government programs for buying fiber and supporting herders. Furthermore, Quelcaya herders unanimously complained about the low price of fiber, which in 2008 was US $ 1 per pound and later the price rose up to US $ 1.5 in mid-2009; these low prices challenge the capacity of the household economy to buy food and goods needed for subsistence, and dramatically diminishes the annual cash incomes.

Other alpaca products are seldom sold—i.e., meat and hides—because it implies culling, which is not done in large part because most of the herders prefer to have large herds. Besides working for the mine, off-farm wage labor is rare in Quelcaya, and if it occurs it is neither a long-term job nor an opportunity for many people. Such labor is mostly in construction.

While a long-standing practice of selling fiber provides a source of cash, another traditional practice gets households access to a yearly supply of basic food—from outside the community—for consumption: bartering livestock for maize and potatoes by traveling in caravans to the agricultural production zones.

Table 5.3. Average herd composition in Quelcaya households.

Specie	**Average**	**Standard Deviation**	**Median**	**Minimum**	**Maximum**
Alpaca	115	92.29	90	0	500
Llama	34	33.39	26	0	195
Sheep	28	25.97	26	0	142
Total	177	136.88	139	0	723

Part of the household's production become commodities—e.g., fiber—generating a cash inflow for the domestic budget. For instance, most Quelcaya families come to the Sunday fair (Fig. 5.14) in the village to buy staples and fresh produce, which have become more available due to the development of road network in the last decade. Some herdsmen will sell animals and/or a little amount of alpaca's fiber to a trader (truck driver). However, households also need goods from outside Quelcaya; thus they travel with a herd of *llamas* to different areas, depending on what they want to obtain in exchange for their products. For instance, they undertake a 8 day round trip to Marcapata district (Quispicanchi province, Cusco, Peru) to obtain *chuño* (freeze-dried potato) around late July, and a 16 day round trip to the town of Ocongate (Quispicanchi province) to procure maize in mid-August. In so doing, bartering provides long-term coverage of food needs, stability facing sudden price surges, and resilience facing climatic changes. Extreme climatic events like droughts and prolonged snow falls may prevent the weekly fair from taking place, thereby hampering food availability.

Maize and potatoes are the core of the herders' diet (Devaux et al. 2009); both crops can be stored for a year, and are consumed until a year after bought. A caravan trip was undertaken by a herder and the author, in August 2010 to Sabancay (Marcapata, Cusco) for bartering llamas by maize; the outcome was as follows: In Sabancay, the herder bartered, with a farmer, two llamas for 272 kg of maize (136 kg each), and the wool of 4 sheep (10 kg) by 27 kg of maize[3]. Thereafter, we had 19 llamas to carry the maize and one for our personal equipment. Knowing that each llama can carry approximately 23 kg of maize (the amount increases when the cargo is less bulky), cargo for 6 llamas was still needed. This cargo was 138 kg of maize that had to be bought for a total of 303.6 soles ($ 108.43 at $ 0.79 per kg) in order for all the llamas to be fully loaded. Though barter and buying/selling co-exist in these encounters of herdsmen and peasants (Ricard Lanata and Valdivia Corrales 2009; Inamura 1986; Orlove 1986), bartering was preferred by this herder, and he only bought maize when he did not have llamas to trade. This preference was based on the better terms of exchange of bartering. For instance, a llama can be sold for a price ranging from 220-250 *soles* ($ 78.50 to $ 89.00)[4]; obtaining enough money to buy 113.6 kg of maize, whereas through bartering the herder obtained 136 kg per animal. Thus, bartering gives 22 kg more than buying.

[3] Here, the relevant amount was the number of sheep sheared rather than the weight of the wool. It is worth noting that this was a marginal transaction within the whole barter, in which the live *llamas* were the significant good.

[4] The exchange rate at the time of the caravan was US $ 1 = 2.8 soles

Figure 5.14. One of the two trucks of the traders in the weekly Sunday fair in Quelcaya.

Livestock husbandry

Production and consumption of the household are based upon livestock husbandry, which in turn, requires mobility patterns that consider the need to feed the flock. Fulfilling this task entails the knowledge of the different needs and forage preferences of the mixed flock, the season (rainy or dry), the number of pasturelands allocated to the household by the extended family, and the situation of the available forage in each pastureland. Though the household owns the livestock, it has different levels of autonomy regarding herding activities, which depend on the extended family's herding tradition, the household's position within the extended family, and the extended family's strategies for facing stressors and needs. For instance, the households' livestock may graze all together or separated by household; similarly, the grazing areas may be allocated following a rotation among households within the extended family. During field work there were interviewees who said that decisions are made by the head of the households of the extended family, whereas others interviewees stated that they decided alone. Based on the interviews Table 5.4 shows a calendar of the activities that the raising of alpaca entails along the year.

Table 5.4. Annual calendar of alpaca raising

Months (1: Jan; 12: Dec.)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Birthing												
Mating												
Medication*												
Castration*												
Weaning*												
Selection for selling												
Shearing												

* Only for herders that carry out modern livestock management

In Quelcaya, the average number of pastureland per household is 2.25, with a standard deviation of 1.06, and the range of pastureland per family is from zero to six (Table 5.5). To have access to pasturelands is crucial for the seasonal mobility of the livestock. When a family controls only one pastureland the herder moves the flock from one grazing area to another within the same area. The time the herd spent at each grazing area depends on the distance to water, quality of the grass, and size of the area. I call this mobility pattern “limited transhumance” because it is more limited in scope than the regular transhumance (Murra 2002; Browman 1974; Murra 1965). Some households that only have one pastureland in Quelcaya may lease pasturelands in the community; if this not possible, livestock may be driven outside the community to pastures that are either owned by in-laws or leased.

Table 5.5. Pastureland per Household (n=91)

Average	St. Dev.	Min.	Max
2.25	1.06	0	6

When a household has access to two or more pasturelands, some are used in the rainy season (December through March) and the others are used in the dry season (April through November). In general, the pasture used in the rainy season is located at a lower elevation than the dry season pastureland because there are more wetlands in the lowlands during this season due to rain. However, there are exceptions in which dry season grazing areas are located at lower elevation because there are water sources nearby (e.g., lake and spring). The higher elevation sites are also more risky for young animals (usually born in December and January) as the young animals can drown in lakes or channels, get stuck in boggy sites, or freeze due to low temperatures. In the dry season the flock is shifted to the higher elevation pasture so that they can graze in the wetlands or in pastures irrigated by springs or by glacier meltwater. This pattern of seasonal mobility has been found elsewhere in the Andes (Salas Carreño 2008; Sendón 2005a; Flores Ochoa and Kobayashi 2000; Browman 1987b; McCorkle 1987; Orlove 1982; Browman 1974; Flores Ochoa 1968) and also elsewhere in the world (Barnard and Wendrich 2008; Barfield 1993; Dyson-Hudson and Dyson-Hudson 1980).

Supra household organizations

Though the household is the basic social unit of production and consumption, the extended family controls the land use, whereas the community is the unit for formal land tenure because it alone has the title for the land of the study area. However, there are other organizations in between household and community, which I call supra household organizations (McCorkle 1987; Guillet 1978). These organizations involve different groups of households, whose participation is sometimes voluntary, whereas in some cases the community decides on the level of household involvement.

The supra household organizations have different responsibility and time of existence (see Table 5.6 for the organizations found in the 2008-2009 period). There are units whose nature is productive as their function is to undertake a productive activity (e.g., Barrios Napurí and Padrón Castillo 1986); other units are formed to maintain or build infrastructure (for an example of committees of irrigators see: Bolin 1990); while other units have to take care of official businesses of the community with government agencies. Though most of the committees are appointed to carry out functions during one or two years, there are also ad-hoc commissions, which undertake specific tasks (Rodríguez and Pascual 2004). In Quelcaya, for instance, there is a vicuña committee, which is appointed annually to organize the round-up and shearing of vicuñas (Fig. 5.15), sell the fiber, and distribute the money amongst herders. There was a "tin roof" commission, which was in charge of buying, transporting and distributing tin roofs for alpaca shelters.

The organization of committees and commissions of these types bears some aspects worth noting: 1) the collective decision-making and responsibility taking; 2) the constant and dynamic household-community relationships; and 3) the collective accountability to commissions and committees. There are two supra household organizations that have been particularly relevant to Quelcaya pastoralists: the extended family and the *ronda*, the former is traditional whereas the latter is of recent origin.

Table 5.6. Supra household organizations in Quelcaya in 2008-2009

Supra household organization	Responsibility
Ronda	Security and justice
Mother's club	Organize women
Association of alpaca producers	Organize alpaca breeders
Association of producers of alpaca studs	Genetic improvement of livestock
Committee of children breakfast (cup of milk)	Childhood nutrition
Parents' association	Support educative work of school
Committee of program "Juntos"	Organize beneficiaries of governmental subsidy
Committee of vicuña	Organize vicuña shearing, and fiber selling
Committee of husbandry	Herding of communal livestock
Committee of agriculture	Allocation of land for agriculture
Committee of fair	Determine fair location, and control transportation price
Committee of sports	Organize sports

The extended family

The extended family is a group of families that share not only a common ancestor, but also land and, sometimes, livestock. In Quelcaya, households of an extended family tend to live in a cluster of houses (Fig. 5.16) and have dispersed huts in the seasonal grazing areas (Fig. 5.17). This pattern of house location has been seen in other pastoralist societies in the Andes (Sendón 2005b; McCorkle 1987). To have common resources among households is based upon consuetudinary rights transferred from generation to generation. The extended family also decides on household herding activities and allocates grazing areas among the households of the extended family. Furthermore, there is cooperation amongst households of the extended family; for instance in building a house. Thus, nuclear families in an extended family need to coordinate and organize herding activities, pasture use to feed the herds, and labor force allocation to carry out herding and other activities.

Figure 5.15. Planting posts for the vicuña round-up organized by the Vicuña shearing committee.

The degrees of coordination and organization vary amongst extended families. A high degree of coordination, within extended families, was observed by the cases of herds of the households grazing together so the heads of the households do not decide individually which pastureland will be use. Furthermore, the herding is undertaken by turns per each household. In some cases, it is decided that a herder will be hired and his wage will be distributed among the households of the extended family. The interviewees explained that the decisions are made, chiefly, by the men of the family. However, also according to the interviews, the head of the extended family—e.g., father or oldest brother—usually has an opinion that carries more weight and authority. There are also cases in which women participate in the decisions, for instance the wife of the head of the extended family, or sisters of the head of the households. A different coordination was explained to me by an interviewee who had taken care of his sister's livestock. Although he decides over his sisters' livestock, he has to coordinate with his father to graze in the extended family pastureland. Further, he also has to coordinate with his in-laws for seasonal visits to their pasturelands. There are also cases in which the household act as independent units. In an interview, a herder explained that he does not coordinate with anybody, and that it is better in this way because he can decide where to graze his livestock. Another benefit for him was that his animals do not mix with others that may carry diseases. Though extended families are kinship units, there are internal tensions and discrepancies based on the interests, needs, and preferences of the households that form them.

Figure 5.16. Cluster of households of an extended family.

The ronda

The *ronda* is the night-guard committee or community patrol. It was organized in hundreds of communities originally as communal protection against modern livestock rustling (for a description of Peruvian rondas see Starn 1999; Nuñez Palomino 1996). The ronda of Quelcaya started as a *Comite de Autodefensa*[5] (committee for self-defense) in the late 1980s. At some point between 1991 and 1992 the *comite* of Quelcaya signed an

[5] These committees were somewhat less dependent on the government than the patrols in Guatemala. For more on this subject see: (for a comparison between Guatemala and Peru's committees see: Fumerton and Remijnse 2004; Remijnse 2002)

Figure 5.17. Hut in grazing area.

agreement or mutual cooperation with the *comite* Juan Velasco Alvarado from Phinaya (neighboring community in the department of Cusco). The Quelcaya committee was linked to and had meetings with organizations in Cusco for a year; even with the *Central Patacalasaya* in Sicuani (capital of Canchis province in the department of Cusco). Current *ronderos* of Quelcaya still remember that these meetings, for strategic reasons, were held on mountain summits or large open flat unpopulated areas; therefore it prevented that livestock rustlers and terrorists locate *ronderos*' domiciles ("ladrones y terroristas ubiquen nuestras casas"). During the meetings guards were kept at the surrounding hills to see who was coming at long distances. In 1995 the Quelcaya committee signed an agreement with Pacaje (a community in Carabaya that already had formed a *ronda*) to form the *ronda* of Quelcaya and to be part of a larger organization of *rondas* hosted at Pacaje. Later, the *rondas* in Puno formed higher hierarchical levels of organization by district, province, department, and macro-south. The macro-south involves departmental organization of *rondas* from Arequipa, Cusco, Moquegua, and Apurimac.

The main function of the Quelcaya *comite* and then the *ronda* was to fight livestock rustlers and vicuña hunters. This function was carried out quite successfully; vicuña hunting vanished while livestock rustling has been significantly curtailed. Furthermore, the *ronda* also kept most of the political violence, then affecting Peru, out of the community[6] (for the key role played by the rondas in defeating Shining Path see: Degregori 1998; Degregori et al. 1996). This communal organization—i.e., the *ronda*, has shown an important evolution from its inception, as well as an expansion from its original function. The success of the *ronda* in controlling livestock-related crime and political violence was a crucial element for the increasing number of functions under its jurisdiction nowadays. However, the current legitimacy of the *ronda* is based on two aspects. The first is the collective nature of the *ronda*: any man and woman (older than 18 years) can be a member, and judicial processes are open to the public. The second aspect is the perception of effectiveness and fairness when enforcing the law, administering justice, and applying punishment. In an interview during fieldwork in 2009, a member of the *ronda* remembered how they proceeded when they captured a vicuña poacher:

[6] The Shining Path (SP) was excluded from my dissertation research for several reasons: 1) it is still a very sensitive topic; 2) there may be members of households in Quelcaya who participated in the SP; and 3) asking questions on the topic could generate discomfort and mistrust in the interviewees, which could hamper the fieldwork.

> “(…) nos han avisado de que había unas vicuñas muertas, (…) hemos salido a buscarles y al toque le hemos agarrado, capturado lo hemos tenido, de ahí su juicio le hemos hecho, su sanción le ha caído, castigo hemos aplicado y le hemos soltado. Así a un montón hasta que ya no hay más cazadores furtivos”
>
> “(…) someone let us know that there were some dead vicuñas, (…) we [the *ronda*] went out to look for them [the hunters] and we quickly captured them, we had them, then we judged them, sanctioned them and applied their punishment, and then we let them go. Like that, we did to many others until there were no more poachers”

In solving concrete problems and bringing justice through a communal institution within the legal framework, the *ronda* expresses a communal flexibility in devising institutional solutions. Further, the *ronda* gained legitimacy because of it was effective (i.e., solving problems) and brought justice to the community. These two aspects were more noticeable when the herders contrasted the *ronda* with the official judicial system. For the herders, the latter is not only corrupt but unfair and expensive. For instance, when a judge was needed in the community for removal of a corpse, as was the case two times during my fieldwork due to two deaths, the family members or the community had to pay for the transportation of the judge from the capital of the province. Hence, the *ronda* is a local participatory legal system that the herders believe serves them better than the official that exist in the far off urban world.

Community

Quelcaya is a community of approximately 660 inhabitants living on an area of 31,358.26 ha. It legally was designated a peasant community in May 30th 1988 (through resolution R.D 0231-88-UAD-XXI-P). According to the interviews, there were four founders of the community who donated land and livestock, and these donations constituted the first communal assets. Two of the founders were designated to lead the process of formation of the community—i.e., preparing the documentation and submitting it to the proper government offices. When interviewed, these two founders stated that the community was formed to benefit from the program of redistribution of land, which the central government undertook in the late 1980s. The program's goal was to distribute land of cooperatives and Agrarian Societies of Social Interest (SAIS) to peasant communities; in Puno department, the program allocated more than one million hectares (Trivelli 1992; Taylor 1987). Quelcaya did not obtain any land because they filed the application to receive lands after the deadline. However, by forming the community the family land-rights were turned over to the community, which became the only landowner and possesses the land title. In so doing, the community formally owns the land; however, the families have kept control and access of the land. Furthermore, the only part of the territory that everybody recognized as owned by the community is the shared land, donated by the community's founders.

The community's governing body is the board, with its 8 members (president, vice-president, secretary, treasurer, and 4 vocals) that are elected every two years. Communal decisions, like in the rest of peasant communities in Peru, are taken in assembly, which takes place monthly or more often if necessary. The common steps of the decision making process about an issue are as follows: 1) Explanation of the issue; 2) Open discussion of the positions about the issue; 3) Summary of positions; 4) Voting on the positions. The importance of the assembly is reflected by the fact that attendance is taken and fines are issued for unjustified absences. The agenda of the assembly is defined by the board, proposed by the secretary and voted on. New businesses not included in the agenda are suggested and voted on to be considered an agenda point.

I will illustrate the decision making process using my own experience prior to the start of my fieldwork in Quelcaya. In order to carried out my field work the authorization of the community was needed, therefore I followed these steps: 1) Visited the community a Sunday when an assembly was taking place; 2) Asked for adding an item in the agenda of the assembly to explain my research; 3) Once included in the agenda, I waited until I was invited to participate in the assembly to introduce myself and to describe in detail what activities the field work would entail; 4) Responded to questions from the community members about the duration and purpose of the field work; 5) Voted on accepting or denying permission to carry out field work; 6) After the assembly accepted giving me permission, I left the assembly room for it continue its other item and had to come back at the end to sign the minutes of the assembly. I had to follow this process twice because the field work was carried out during the administration of two different community boards. Orlove (2009) followed a shorter version of this procedure for a short visit to the community Phinaya (department of Cusco).

Herders and environmental change

Quelcaya herders have perceived climatic changes, and consequently, they have responded to specific climatic events and changes. This sub-section will show both the perceived changes and the responses of herders to what they consider the most important effects of climate change. No statistically significant relationship (with a p-value of less than 0.05) was found between any household demographic and socio-economic characteristics and household responses to climate change. The statistical tests used were chi-square and t-test. This lack of significance may be due to the homogeneity of the community because the households all lived in similar socio-economic conditions (for example, there was very little variation in education level between households: 94.7% of male heads of the household did not complete secondary school, and 74.7% did not complete primary school. Among women, the education levels were even lower; only 21.7% of women had even completed primary school, and no women had completed their secondary education). The homogeneity also points to the fact that this community is in fact a community that develops strategies to face environmental change collectively and has fairly uniform access to resources like education. As a community, they face the same environmental conditions, the same external stressors, and as a result, have a similar way of life.

The Quelcaya population perceives climatic changes mostly through three different ways: 1) glacier retreat, 2) an increase of extreme temperatures, warmer during the day and colder at night, and 3) shifts in the rainy season, with a shorter length and more abrupt changes from intense rain to dry days. These perceptions might be reinforced by the fact that temperatures have been rising not only in the dry months (cloudless skies and more direct sun radiation) but also in the wet months that have more cloud cover and in which less warmth is expected during the day. For the meteorological data see *climate*, in the section *Three exogenous drivers of social and environmental change for Quelcaya* in this chapter.

Based on the interviews, I found that perceptions are influenced by age and gender. For instance elderly members of Quelcaya have seen the glacier recession; they remember that the glacier had a larger extent and that they played with snow as children. It is a general perception amongst the elderly that the climate used to be nicer ("más bonito era antes…"). An interview of an elderly man evoked his memories about how he used to play with the snow next to his parent's hut; he also remembered that the glacier snout near his parents' hut had a larger extent, reaching almost the current location of the wetlands. Similarly, women have perceived springs changing location and runoff quantity, probably because they have to graze the livestock in pastures with forage and water. When interviewed, a woman complained that the spring that used to be nearby had gone dry; she described this as if the spring had run away and left them ("el manantial se ha corrido y nos ha dejado"). The men have also noticed changes in the springs because they have to build the channels to irrigate pastures and wetlands. Men interviewed complained because they had to build the ditch further uphill where the spring had moved ("pucha, más arriba tenemos que poner el canal donde ahora está el manante").

Perceived changes in temperature and precipitation are manifested through more freezing-nights, larger droughts, and floods; these were the effects to which the herders responded. Before going into the specific responses, some general patterns are first mentioned. There were two common responses to all the effects of climate change: moving the animals and providing medication (vitamins, antibiotics, and medicinal herbs). The fact that moving the animals is a generalized response underlines the importance for adaptive capacity of been able to carry out the "limited transhumance" and having access to different grazing areas (see *Livestock husbandry* in this chapter). Further, the generalized use of medicine (Western and traditional) points to the capacity of the herders to combine different types of knowledge. The use of herbs sheds light on the existence of traditional knowledge in this pastoralist culture; this knowledge is communicated from generation to generation. The western knowledge may be obtained through relationships with veterinarians in livestock shows or, in the past, with the veterinarian of the former neighboring *hacienda*.

The occurrence of freezing-nights is an effect of climate change that most of the population did not respond to (Fig. 5.18). The generalized lack of response to freezing-nights may indicate some resignation facing this event as well as confidence in the livestock's resilience to harsh environmental conditions. However, some herders indicated that they responded by using sweaters and blankets to cover to the baby alpacas, and by moving the animals to available shelters at night. Furthermore, freezing-nights kill the plants, thus pasture availability diminished. In order to cope with limited pastures, the herders will look for pastures with running water because it prevents ice formation; similarly, running water maintains vegetation unfrozen.

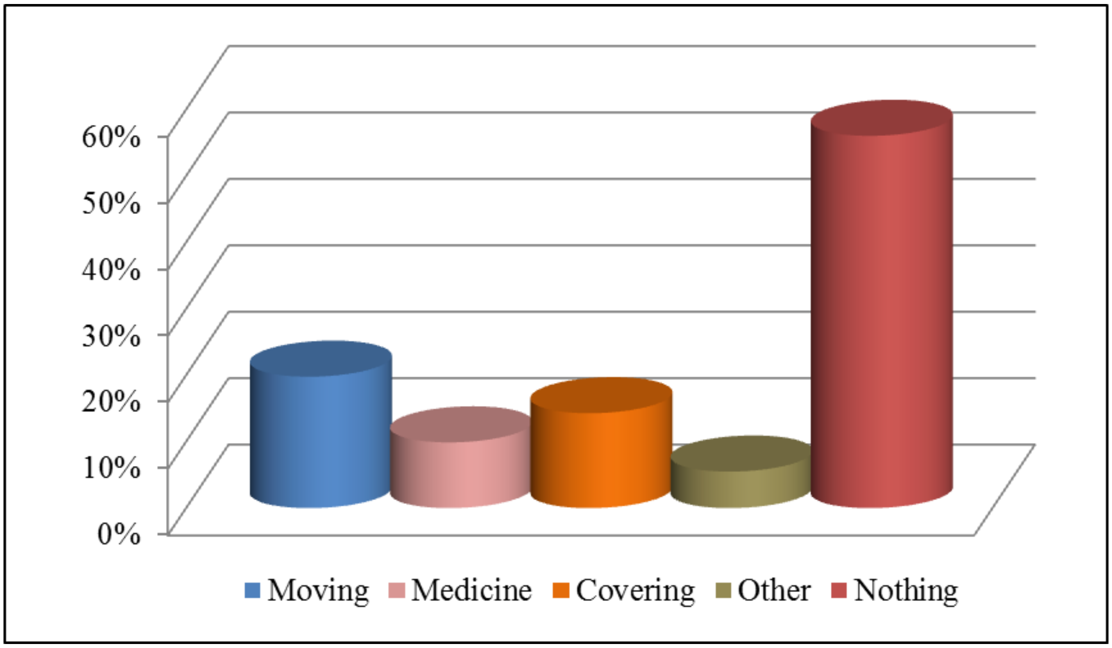


Figure 5.18. Percentage of responses to freezing-nights (n=91). Total adds up to more than 100% because more than one response was allowed.

To respond to droughts and limited pasture available for the flock, herders will divert water ("*jalar el agua*") from springs, rivers, and lakes, by building and extending rustic channels (Fig. 5.19). The diverted water is used to irrigate pastures and generate wetlands (for irrigation without agriculture see: Steward 1933; Steward 1929); the herders will take the animals to these irrigated wetlands when forage becomes scarce during the dry season. According to the herders, another effect of irrigating is that it keeps pastures wet and firm in the soil; therefore strong winds cannot uproot them. Further, the increasing precipitation variability has enhanced the importance of the management of rustic channels in maintaining pastures and wetlands for the dry season.

An effect of climate events perceived by the herders is flooding, which happens in the rainy season. The interviewees said that flooding is caused by overflowing of lakes, rivers, and channels. Lakes overflow because of increased water volume; this higher amount of water can break lake margins causing floods. Rivers overflow their banks due to increased water volume, landslides that either block their natural courses or cause an abrupt increment in the river volume. A third type of flooding, according to the herders, is caused by broken or blocked dirt channels. The flooding is especially negative when it affects corrals and other sleeping areas for the livestock. The most common response (Fig. 5.21) to flooding is moving the livestock to dry areas, usually located at higher ground or on sandy soils; these soils have higher percolation levels and thus tend to remain dry. The movement of the animals to dry areas is particularly important because it precludes the livestock from sleeping on wet ground. Herders think that if the livestock sleeps on wet ground it increases the likelihood of getting a disease.

The responses of households to effects of climate change were not statistically significant ($p>0.05$) with any of the following variables: age and educative level of the couple head of the household; total labor force available in the household (household members > 6 years old) and by gender; herd composition and number of grazing areas accessed.

Though most of the responses to climate change effects showed before are carried out by households, there are also responses organized by the extended family. For instance, extended families and groups of households build channels and monitor water flowing in the channels. Channels usually are several kilometers long, so to build a channel often involves the labor force and cooperation of multiple households over several years. Monitoring is important considering that the channels are rustic ditches, which can be broken or blocked hampering the irrigation of pastures.

Figure 5.19. Channel diverting water to irrigate wetlands, community Quelcaya.

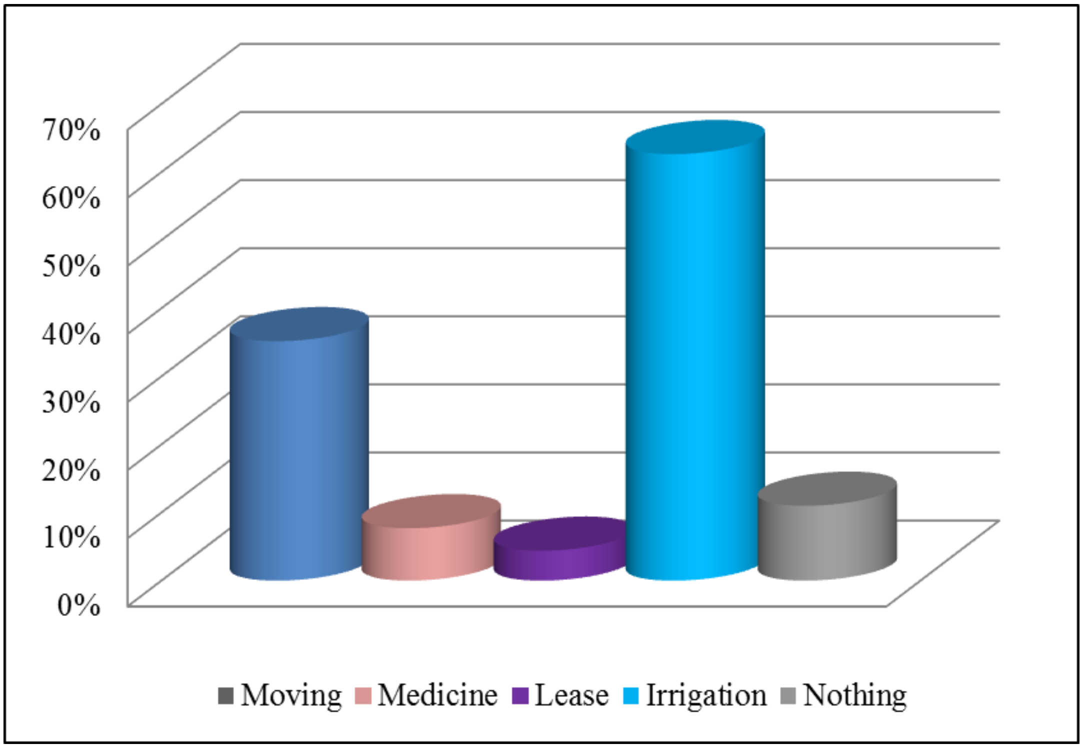


Figure 5.20. Percentage of responses to drought (n=91). Total adds up to more than 100% because more than one response was allowed.

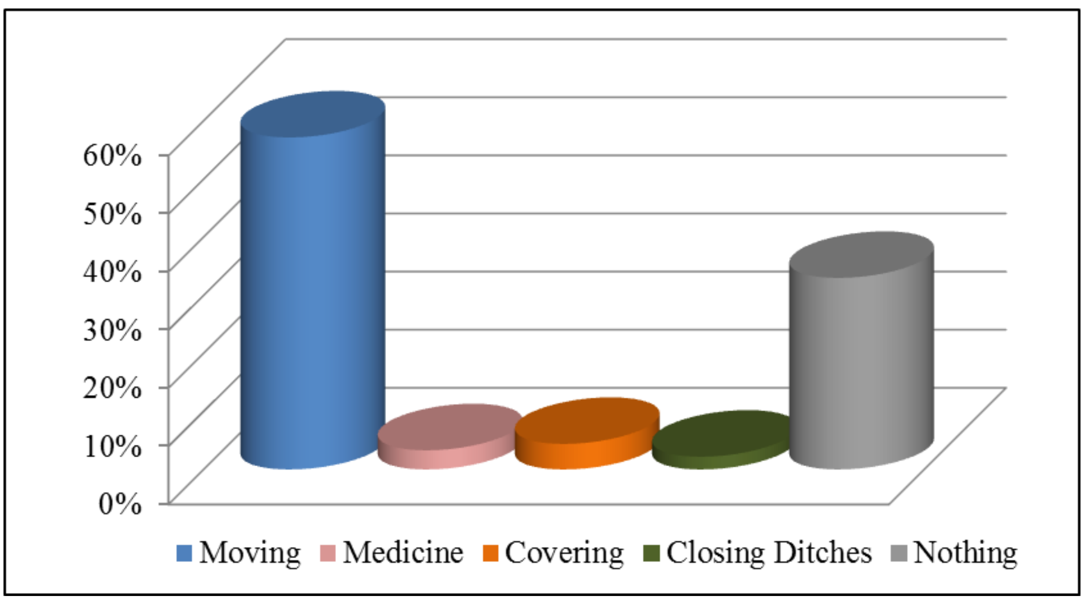


Figure 5.21. Percentage of responses to flooding (n=91). Total adds up to more than 100% because more than one response was allowed.

At higher organizational levels than the extended family there were not specific responses observed to climate change. However, there were communal activities and works to undertake major tasks such as road improvement and maintenance (Fig. 5.22), infrastructure building, and vicuña round up (Fig. 5.15). The existence of these communal activities may be an indication of the possibility of communal responses, if effects of climate change configure major threats to the community. The capacity of individuals and communities to access resources and capitals (e.g., human, social) to respond to changing conditions has been documented for the Andes (Valdivia et al. 2010; Stadel 2008; Young and Lipton 2006; Bebbington 2001). Yet, further research may determine what conditions may trigger these responses or under what conditions thresholds are surpassed, thus communal response is triggered. Further, this understanding may serve as foundation for larger generalizations on communities' responses in facing climate change, as well as for design adaptation and development policies (Stadel 2008; Young and Lipton 2006).

CONCLUDING REMARKS TO OPEN A DISCUSSION

Quelcaya has been responding to climatic, social and political changes along its more than 100 years of history. These changes have the form of pulses and presses, or sudden discrete, and sustain chronic events respectively (Collins et al. 2011). Responses to pulses, presses and the interaction of both, have been implemented by households, supra household organizations, and the whole community. However, these three types of response have not always tackled the same change or event—climatic, social, or political—or at the same time. Further, some communal responses are implemented by a supra household group like an *ad hoc* committee, others by the whole community, by the *ronda*, and there are also responses carried out individually by households.

Quelcaya is a community with formal property of the land since 1988; however, the extended families have controlled and accessed the land at least since 1863. Therefore, the communal property of land and the family usufruct of land constitute a dual tenure regime. This overlapping of tenure regimes has caused tensions between households and the community regarding the distribution of benefits from mining activity. For instance, households directly impacted by the activities of the mining company claim that they should receive higher compensations than the rest of the households, which received equally allocated shares of the payments of the company to the community. Despite tensions, the community members also share a history of living in the area and kinship links have been established along the years. For instance, an important part of this shared history is the failed attempt to expand the community's territory by benefiting from the land redistribution process, which led on one hand to the creation of the community, and on the other to the loss of property rights from the families. Further, when legal actions or mayor infrastructure work are needed it is the community that makes decisions and acts upon them. For example, agreements with government agencies or mining companies are voted on and decided in community assemblies that require a minimum number of attendees to be legitimate.

Figure 5.22. Women working on widening a path.

Climate change effects are stressors for the life of Quelcaya herders. In general, herders perceived these effects as hasher climatic conditions than the usual climatic variability of the Andes. Climate change has also been registered through meteorological data as shown earlier in this chapter. Quelcaya's population has been responding to climatic variations mostly through household and extended family actions. Whether the former or the latter responded depend on the type of response needed, and how fast the response should be implemented. Hence, households tend to respond to swift changes occurring at a small scale; therefore implementing immediate actions that not require coordination with other households. For instance, households in Quelcaya have responded to effects of climate change like freezing nights and droughts by moving the livestock to unaffected pastures, using medicines, irrigating grazing areas, and sheltering the animals. These responses imply land-use decisions and modification, land-cover changes, and herds' mobility patterns also found in Andean herders elsewhere (Flores Ochoa and Kobayashi 2000; Browman 1987a; Orlove 1982; Webster 1973). Extended families respond to slow changes impacting large areas; thus responses require coordinating actions amongst several families. The channels to irrigate grazing area exemplify not only a response to a large scale effect like a drought but also the need to coordinate amongst several households by whose lands the channel passes by and/or will be irrigated. Chapin and colleagues (Chapin III et al. 2006) showed that in interior Alaska, institutional responses to effects of climate change on ecosystem services focus on short-term single impacts—like responses of Quelcaya households. Further, Chapin argued for the need of a cohesive policy response to climate warming, which address "linkages to the supporting services that govern long-term trend or unexpected changes…" (Chapin III et al. 2006, p. 16640).

An indirect effect of climate change on Quelcaya may be the development of agriculture at higher elevations due to rising temperatures; this effect has been seen elsewhere in the Andes (Araujo 2009; Araujo 2008; Halloy et al. 2006). It can be hypothesized that this potential impact on the expansion of agriculture frontier may benefit pastoralists if only by diversifying their economic activities. However, it might be a threat for Quelcaya pastoralists by: 1) expansion of agriculture, especially in the lower parts of the community, hence raising irrigation needs; 2) increased competition amongst different water uses; 3) pastures converted into crop fields may lead to livestock displaced to upwards to more marginal and elevated land, wherein they will face harsher environmental conditions. Similar increasing pressures on water have been hypothesized for the Cordillera Blanca in Peru (Chevallier et al. 2011). In order to understand such interactions between pastoralism and climate change, research is needed, as well as an analytical framework linking climate change impacts on subsistence production, on one side, with state-of-the-art biological studies of climate change impacts on cultures and breeds of subsistence economy, on the other side (Morton 2007).

The fiber price has been, for a long time, a very important issue for the herders (Jacobsen 1993; Burga and Reátegui 1981; Thorp and Bertram 1978). The fiber is the main and steadiest source of cash for the household budget. This importance is reflected in two ways. First, the herders are talking constantly about the price of the fiber, wondering if it has drop, and whether it is a good time to sell. Second, the herders were up to date about the fluctuations of the national fiber market through information from their relatives in Macusani. Further, this information enabled them to bargain better with the local trader when selling their fiber. By knowing the price the herders calculate the trader's profit, which in turn allowed them to ask the trader to diminish his profit—i.e., not to be too greedy—and to argue for a higher price.

In the alpaca-fiber commodity chain, the demand not only controls the price but also the quality and preferred color of the fiber. It is the coupled fashion-textile industry that determines whether white or colored fiber is preferred and if the color should be natural. Thus, these preferences are set at one end of the chain and from there they are transferred to the rest of components of the chain. At the other end of the chain are the producers—i.e., herders—that receive the message of the preference through distinctive signals from the market, and more specifically through the intermediaries' preferences articulated in the phrases "that is what the market wants" ("eso es lo que quiere el mercado") or "that is what the industry is buying now" ("eso es lo que la industria está comprando ahora"). The power of the demand in this chain impacts directly the producers and drives the composition of the herds. In so doing, it enables a process of selection by the market (Frank et al. 2006), which impacts the genetics of alpaca. For instance there has been a "whitening" of the herd. Similarly, the preference of the market for the fleece of the breed type *huacaya* has caused that the alpaca *suri* breed substantially diminished its presence in the high Andean landscapes (Enríquez Salas 2006).

The herders keep the livestock until the alpacas are of old age to overcome demographic characteristics of the specie—i.e., low birth and high mortality rates. In so doing, the herders influence the process of selection (León-Velarde and Guerrero 2001) because there is no selective culling of animals. Other ways of influence the genetics of the breed are slaughtering animals for food, castration, selective breeding, and withdrawing males from the breeding pool to become pack animals (Browman 1974). Additionally, the lack of market incentives for fiber quality discourages herders from investing their scarce capital in improving their flock, or carrying out costly modern livestock management. The importance of alpaca and the lack of stimulus to improve were joined when Quelcaya used money, from a mining payment, to buy tin roofs for four shelters built through communal work in each sector of the community and in the village. These infrastructure improvements are meant to shelter livestock in harsh environmental conditions.

The co-existence of both subsistence and market economy—i.e., barter and cash sell—within Quelcaya's households, diversifies the sources of food-stuff, diminishes the risk of price fluctuations, and prevents households' participation only in market relations, which have, historically, lessened herders' purchasing power (Thorp and Bertram 1978; Orlove 1977). They received less money for their commodities but also face increasing prices of goods produced outside the community (the rate of inflation during the fieldwork was 6.5 %). Decreasing terms of exchange between rural communities and urban products work as negative feedbacks leading to subsistence economy and non-market economic relations. Thus, by having the capability of interchange market and subsistence realms, herders are buffered from price fluctuations, market failures, and decreasing terms of exchange. However, this capacity of interchange will have to be assessed in the future because of the decreasing trend to undertake caravans for barter, and the expansion of road networks that favor traveling on buses to buy in the nearby markets.

It is worth noticing that road network development has enhanced food availability, especially of fresh produce that can be bought in the weekly fair. However, *llamas* have become less useful. This has two consequences: 1) the number of *llamas* is plummeting while the kilometers of asphalt are extending, and 2) the number of caravans undertaken is decreasing (Ricard Lanata and Valdivia Corrales 2009). For instance, this was the last trip that will be undertaken by the herder I traveled with. Some impacts from this development that need further analysis are: 1) the changes in the ecosystem as the animal-pasture interactions are altered by lessened amount of *llamas* grazing (as they prefer different forage species than alpacas and sheep (Bryant, Florez, and Pfister 1989; Wilcox, Bryant, and Belaun Fraga 1987), and 2) the impact on household food security of increasing reliance on market transactions and the weekly fair, rather than to secure year-long supply of potatoes and maize bartered by the herders in Cuzco.

The dual character of Quelcaya's economy shelters households against food price surges. Household production is based on non-market relations; allowing households to withdraw from the market economy and rely on subsistence economy when the market is not advantageous. For instance, households replace cash transactions by bartering to diminish their exposure to market economy. I would argue that households that can navigate between market and subsistence economies are less vulnerable to fast economic changes, and more resilient to long-term processes occurring beyond their limits and control (e.g., decreasing terms of exchange for rural products). However, smallholders elsewhere are increasing their involvement in market relationships, even in the face of unequal power relations, market failures, and differences in capital, knowledge and technology. Amidst this adversity, the return of peasants' social institution and collective action has proven to be the best way to participate in the market economy (Devaux et al. 2009; Markelova et al. 2009).

An increasing number of processes over different time-spans have been threatening pastoralists' way of life (Khazanov 1984) with capitalism, climate change, and land accumulation being the most salient (Postigo, Young, and Crews 2008; Bassett and Turner 2007; Salzman 2004; Ginat and Khazanov 1998; Khazanov 1998; Turner 1993). Though the capitalist expansion of the last twenty years in Peru has not yet pursued the transformation of the domestic farming sustaining peasant production, increasing off-farm labor may bring the herding system to a tipping point. In Quelcaya, wage labor for the mining company may engender social differentiation and labor force shortage. At the same time, changing from herder to wage-worker may trigger major transformations regarding relationship with the land, identity, and pastoralist culture, as has been seen elsewhere (Escobar 2006).

To conclude, allowed me to speculate that in the scenario of increasing extreme climatic events and prevailing conditions of poverty and marginalization, the adaptive capacity of Quelcaya herders to social, political, and climatic changes will be insufficient. Exogenous drivers, acting through pulses or presses (Collins et al. 2011), may pollute water and soils, withdraw the most qualified community members from herding to work in the mine, and hamper institutions; the structure of the fiber commodity chain will keep impoverishing pastoralists and preventing the development of livestock husbandry. In turn, these impacts could act as a feedback on the social-ecological system increasing its instability through processes such as mismanaged livestock keeping; weakened institutions regulating use of water and pastures; and loss of traditional knowledge and identity. All these processes will produce a social-ecological system with a weak adaptive capacity and little resilience facing social-environmental change. Further, peasant communities in general, and pastoralist communities in particular, are marginalized and excluded, which prevents them from being prioritized within government agendas about resilience and adaptation. Another factors making this situation more acute are the lack of policy to strengthen local adaptive capacity (Cancino Borge, Mendoza Nava, and Postigo 2011), and the few initiatives of governmental agencies facing extreme climate events.

The preeminence of socio-economic concerns over the environmental brings the discussion back to the relationship between legacies (Fig. 5.1). The social institutions and organizations have been key path dependencies for the adaptive responses and resilience of the Quelcaya SES facing sustained exogenous stressors. Responses to climate variability and change are based on these key path dependencies in turn. Households, extended families and supra household organizations, and community, are the social organizations that have faced and responded to social-environmental disturbances over time; these are the institutions that are adapting to current climatic changes and that constitute the core elements of a sustainable adaptation in the rural Andes.

Chapter 6: Mismatched and synergic actions in institutional responses to climate change in the Peruvian Southern Andes Region

INTRODUCTION

This chapter examines both the mismatched and potentially synergic actions between the Regional Governments and the peasants as both entities respond to changing climatic conditions in the Peruvian Southern Andes. By examining the potential contradictions (and compatibilities) between the government's and peasants' responses to climate change, the case study of this dissertation—i.e., Quelcaya—locates Quelcaya within a larger regional context.

Landscapes of the Peruvian Southern Andes

The Peruvian Southern Andes (hereafter the study region or the region) encompasses the mountain ranges of Ausangate and Carabaya, glacier dominated valleys and lakes, mountain slopes and the Altiplano plateau (see Fig. 2.2). These complex biophysical landscapes are matched by diverse farming systems, ranging from exclusively pastoralist communities in the high Andean wetlands (Chapter 5 in this dissertation, Jacobsen 1993; Orlove 1982) to commercial farmers in the valley floors and irrigated lands that are expanding the agrarian frontier to the coastal desert (Ertsen, Swiech, and Machicao Pererya 2010; Young 2008; Mayer 2002). On the slopes of the Andes and in the Altiplano, agro-pastoralists have made their livelihoods over millennia through farming systems that combine agriculture and livestock keeping (Zimmerer 1999; Jacobsen 1993; Browman 1989; Orlove 1977). Throughout these livelihood systems there have been dynamic and overlapping institutional arrangements that govern land and water use across multiple spatial-temporal scales (Boelens et al. 2002; Gelles

2000; Zimmerer 2000, 1995; Mitchell and Guillet 1994; Oré 1989). The study region is composed of three departments whose political authorities are called Regional Governments. These governments were created during the decentralization process, which, at the national level, has been the most recent and comprehensive transformation in the architecture of governance through transfers of political and fiscal power and executive capacity from National to Regional governments (O'Neill 2003; World Bank 1997).

The most conspicuous impacts of climate change in Peru are the disappearance of small glaciers—located below 5000 m and glacier recession (Thompson et al. 2006; Thompson et al. 2003). In the study region, the Quelccaya ice cap, located in the cordillera Carabaya, frequently has been used to assess the magnitude of climate change (Buffen et al. 2009; Mark et al. 2002; Thompson 1980; Thompson, Hastenrath, and Morales Arnao 1979). For instance, in the largest glacier outlet of Quelccaya ice cap, Qori Kallis, glacier ablation uncovered fossil plants that were 5200 years old (Gould et al. 2010; Buffen et al. 2009; Thompson et al. 2006). Since 1995, Qori Kallis' glacier recession rate has been ~60m/yr., which is 10 times faster than the glacier's recession rate from 1963 to 1978. Another indication of the amount of change is a 6 ha. proglacial lake that appeared in 1991,which by 2005 had increased to 34 ha. (Thompson et al. 2006).

The magnitude of glacier retreat is an indicator of global climate change (Rosenzweig et al. 2007). In Quelcaya, glacier retreat may increase the amount of runoff in the short-term, which may also cause expansion of pasturelands. In the long-term, however, the effects may reverse, impacting negatively herders' livelihoods. Thus, the impacts of climate change compromise peasants' and farmers' food security and subsistence since their productive capacity is hindered and their livelihoods jeopardized (Anderson, Marengo, et al. 2011; Varillas 2010; FAO 2008). At this point, these impacts point to the need for anticipatory planned responses from the regional government; however, instead the regional governments have chiefly implemented reactive responses and complained about budget limitations. Although people in the highlands are threatened by cold spells every year (RPP 2011; SENAMHI 2011), government responses occur only after-the-fact and have to be implemented every year by emergency programs rather than as proactive initiatives designed to diminish vulnerability. All the authorities interviewed during the fieldwork (2008-2009) for this dissertation project, stated that they had implemented contingency plans to respond to climate change, such as provide blankets to the herders in order to cope with cold spells. However, no authority mentioned plans to diminish vulnerability, for instance a program to build houses for cold climate.

Despite the Andean peasants' millenary tradition of adaptation to climatic variability (Young 2009; Bustamante Becerra 2006; Dillehay 2000; Erickson 1999; Browman 1987a; Murra 1984; Isbell 1978), the intensity and rapid pace of current climatic change and the loss of some productive strategies due to social and economic conditions (Valdivia et al. 2010; Young 2008), are likely to overcome peasants' adaptive capacity and resilient productive strategies (Sperling et al. 2008; Stadel 2008; Adger et al. 2007). It is in this context that this chapter aims to show the responses of peasants and regional authorities to climate change effects, pointing towards areas of competitive and synergic interaction (Press and Blach 2002), and more importantly, showing pathways to bridge these responses to enhance the adaptive capacity and resilience of the region (sensu Valdivia et al. 2010; Stadel 2008; Alley et al. 2003; Cash et al. 2003).

The chapter is organized in five sub-chapters. The first presents and contrasts peasants' perceptions of climate change vis-à-vis meteorological data; the second analyzes how the regional environmental governance has addressed climate change; the third is dedicated to understanding the social-environmental impacts of climate change. In the fourth section, different aspects of the multi-actors' responses to climate change effects are analyzed and integrated. The final section provides a discussion of conclusions based on the analyses presented in the previous sections of the chapter.

PERCEPTIONS OF CLIMATE CHANGE IN THE PERUVIAN SOUTHERN ANDES

This sub-chapter presents perceptions of climate change among agriculturalists, agro-pastoralists, farmers, and herders in the Peruvian Southern Andes. These perceptions are first presented vis-à-vis meteorological data. The peasants' observations of climate change registered in this study are consistent not only with perceptions in other parts of the region (Sperling et al. 2008; Kendall and Chepstow-Lusty 2006) but also with research findings of increased variability and timing shifts of rain for the Peru-Bolivia Altiplano (Seth et al. 2010; Valdivia et al. 2010). As recorded in 29 interviews, informal conversations, and focus groups, peasants have noticed climate change through changes in the precipitation patterns in the past 7 to 9 years. Specifically, they have noticed that: i) the rainy season has become shorter through a delayed onset and an earlier end; and ii) precipitation has become more irregular during the rainy season, with a higher intensity when it rains but with more dry days. In the community Yanque Hurin Saya in Arequipa a peasant explained the change in precipitation as follows:

> (…) antes las primeras lluvias se iniciaban en noviembre, hacia el 25 de diciembre empezaban las lluvias más intensas, poco interrumpidas y bastante parejas, que duraban hasta abril. Ahora, las lluvias empiezan en enero, duran 30 días y se terminan, e incluso en ese tiempo la lluvia es interrumpida con días secos.
>
> (…) the first rains used to start in November, then around December 25 the heavier rains began, which were barely interrupted and pretty consistent until April. Now, the rainy season starts in January, lasts 30 days and it is over and during those 30 days rain is interrupted by dry days (all translations by the author)

In Cabanaconde (Arequipa) a peasant said that "(…) the weather is changed (…) the rainy season has shortened and has become more irregular" (…el clima está cambiado (…) la época de lluvias se ha acortado, y llueve disparejo). The same pattern of changes was found in Cusco, where a peasant from the community of Rosasani said:

> La época de lluvias ha reducido su duración, antes empezaba en octubre/noviembre para el sembrío y duraba hasta abril/mayo, ahora las lluvias se inician en diciembre/enero y se acaban en marzo/abril. La lluvia se ha vuelto irregular, antes llovía parejo, ahora cae una lluvia intensa tipo chaparrón por uno o dos días y luego está seco por varios días.

> The rainy season has shortened in its duration; it used to start in October/November—for sowing season—and last until April/May; now the onset of rainy season is December/January and ends in March/April. Rain has become irregular—it used to rain a constant amount, but now it rains heavily—like pouring rain for one or two days and then it is dry for several days.

Though the onset of the rainy season used to be in August–September, it has become delayed and increasingly unpredictable, thereby challenging peasants' planning of the sowing season and the subsequent activities. Figure 6.1 shows the variability in precipitation at the onset of the rainy season between 1950 and 2009, remarkably in September after late 1980's in Cabanaconde. The quantity of rain in September shows high variability with peaks as high as 43.50, 55.20 and 39.60 in 1976, 1986, and 1997 respectively, and several years with little or no precipitation like 1990-93, 2002-03, 2007-08 that no precipitation was registered, or 2001, and 2004-06 with 7.00, 2.10, 9.80, and 7.90 mm respectively. October is also irregular in terms of rainfall with years of no precipitation registered (1973-76, 1994-94, and in 1985-89 with 1987 registering 13.30 mm) mixed with years of precipitation of 29.70, 34.40, 24.20, 29.90, and 20.30 (1972, 1979, 1984, 1999, and 2000 respectively). It is also noticeable the lower levels overall of precipitation in Cabanaconde than Sicuani and Macusani, which may reflect the drier conditions of Arequipa than Cusco and Puno.

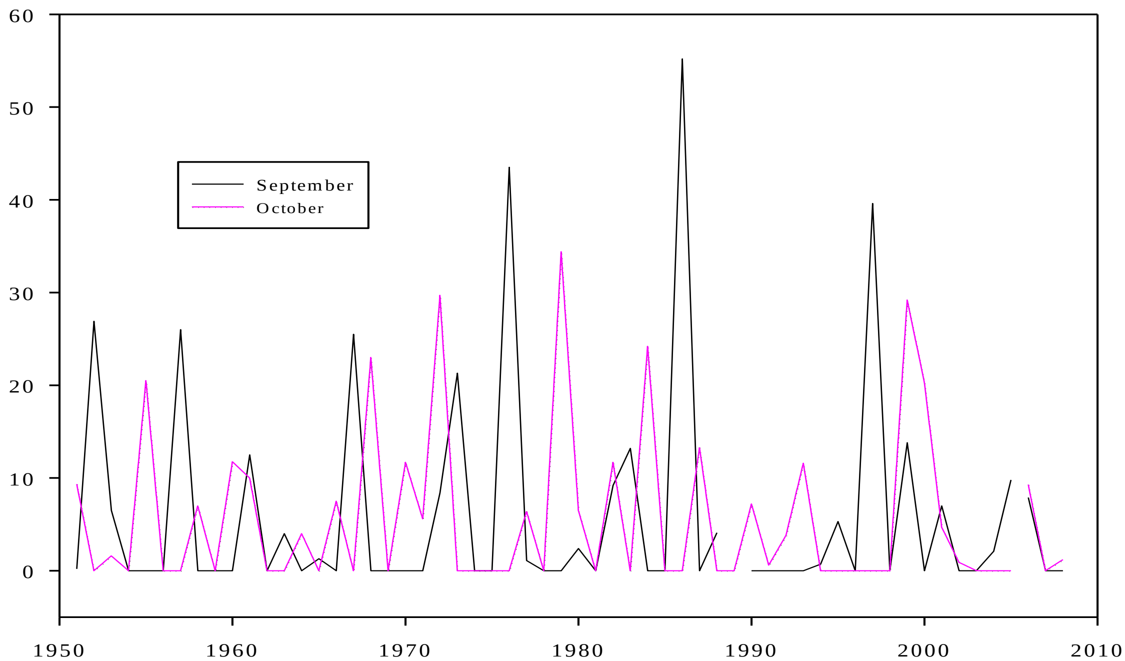


Figure 6.1. Precipitation (mm) of September and October (SO) in Cabanaconde (Caylloma-Arequipa) between 1950 and 2008. These months encompass the onset of the rainy season.
Source: SENAMHI

Figure 6.2 shows a highly variable precipitation between 1993 and 2006 in September and October in Sicuani (Cusco). In the former month it is clear since 2004 when it rained 51.60 mm. The precipitation in October had decreased between 2002 and 2004, and then it increased to 84.10 mm in 2008. It is noteworthy that the delayed onset shown in the meteorological data for September matches peasants' reported perceptions about climatic changes in the region. This suggests that existent local knowledge may be recognized and used by government functionaries in order to protect local peoples from the impacts of climate change or help them adapt.

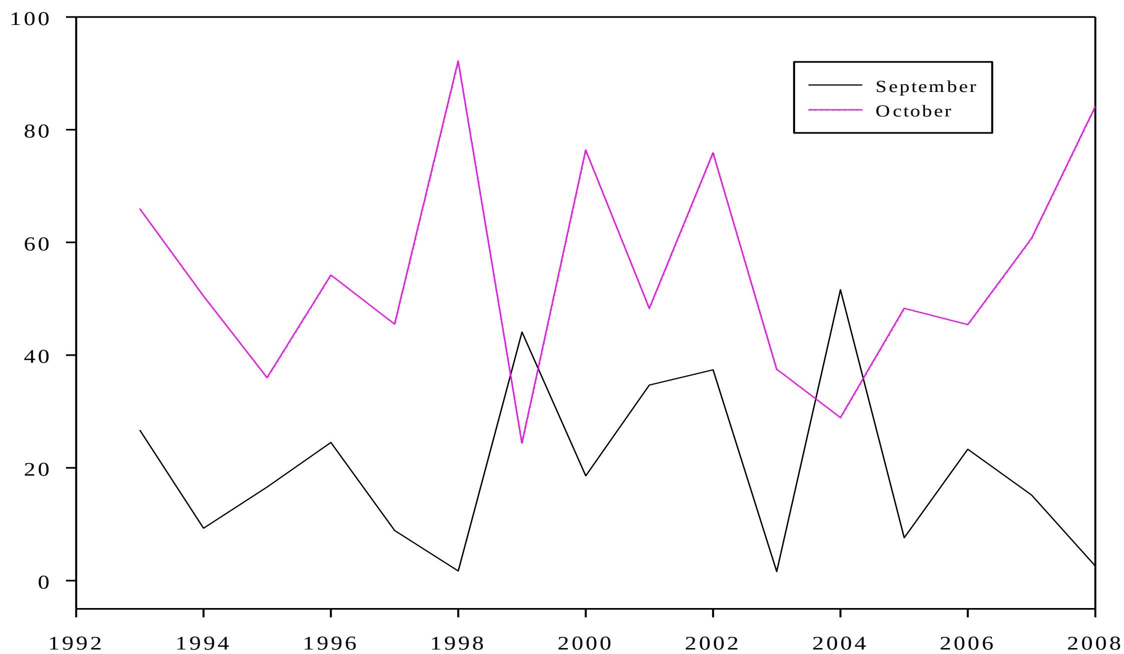


Figure 6.2. Precipitation (mm) of September and October (SO) in Sicuani (Cusco) between 1993 and 2008. These months encompass the onset of the rainy season.
Source: SENAMHI

The season of snow fall has also experienced changes. Specifically it has become almost nonexistent in some areas and erratic in other parts of the region. Peasants also perceive variations in the average daytime and nighttime temperatures. They report experiencing colder nighttime temperatures and warmer daytime ones, which is consistent with research on temperature variations arising from evapotranspiration (Thibeault, Seth, and Garcia 2010; Valdivia et al. 2010; Sperling et al. 2008). Peasants consistently report perceiving these changes in temperature across the study area. The peasants perceived that days are warmer and nights are colder. In the Cabanaconde community, a peasant from the Villa Colca water commission said that "(…) both heat during day and cold at night have increased" (los dos, el calor en el día y el frío en la noche han aumentado). In the community Yanque Hurin Saya, peasants perceived the same pattern of intensified extreme temperature but added that “the intense cold at dawn hampers crop growth” (“el intenso frío del amanecer impide el crecimiento de los cultivos”); this is consistent with meteorological data in Sicuani (see figs. 6.3 to 6.6). Furthermore, based on records, hydrologist of the Regional Government in Puno reported that in 1970 the maximum evapotranspiration was 1100 mm and in 2007 it was 1700–1800 mm. In the period of 1960–1990 the annual average rainfall in the highlands was 580–620 mm, and in 2007 it was 540–550 mm. In the 70s and 80s, the season when freezing nights occurred used to be in June–August with temperatures down to -9°C; however, currently freezing nights occur in February and the temperatures drop to -22°C. In Arequipa, in July, two months before my fieldwork, many alpaca died because of a substantial snow fall that covered the pastures for several days and prevented grazing. Peasants from Arequipa remembered an unusual freezing night in early September 2009, where “(…) it was as if the cold spell had feet and choose its path leaving a wave-like pattern on the ground impacting this crop but not the one next to it” (“era como si la helada tuviera pies y escogiera por donde ir haciendo curvas, le afectaba a la planta aquí y no a la de su costado”).

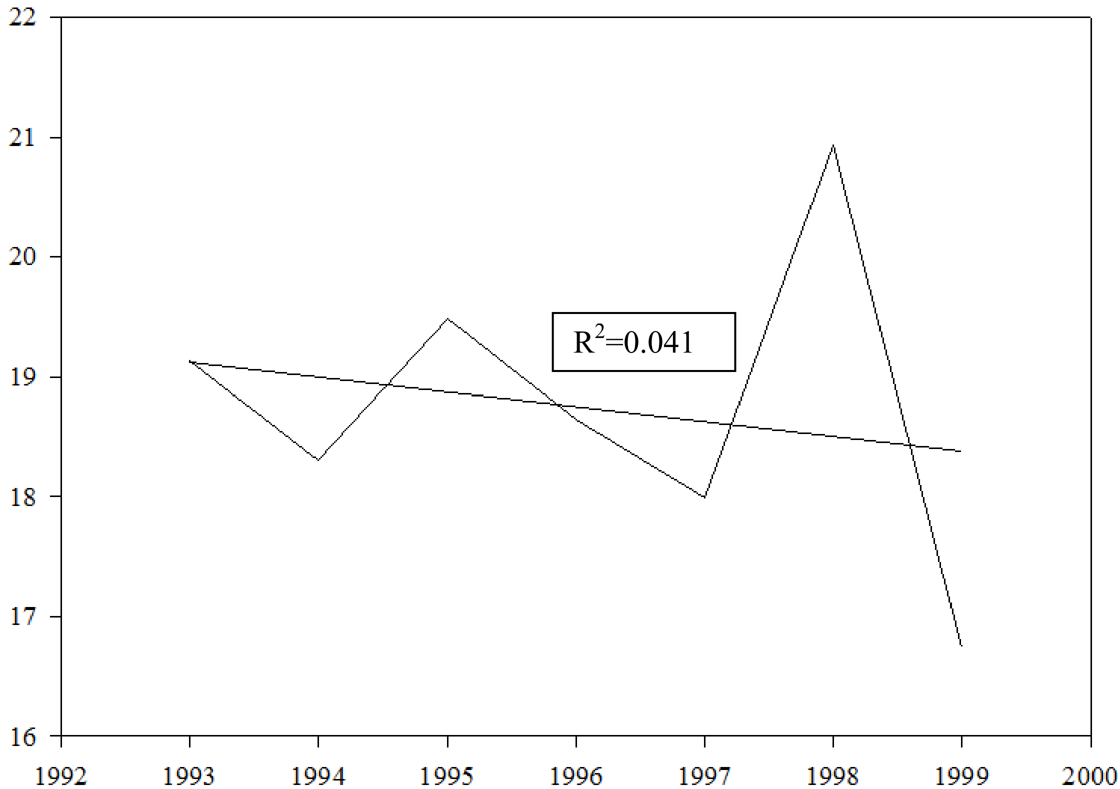


Figure 6.3. Trendline of maximum temperature (°C) in Sicuani between 1993 and 1998
Source: SENAMHI

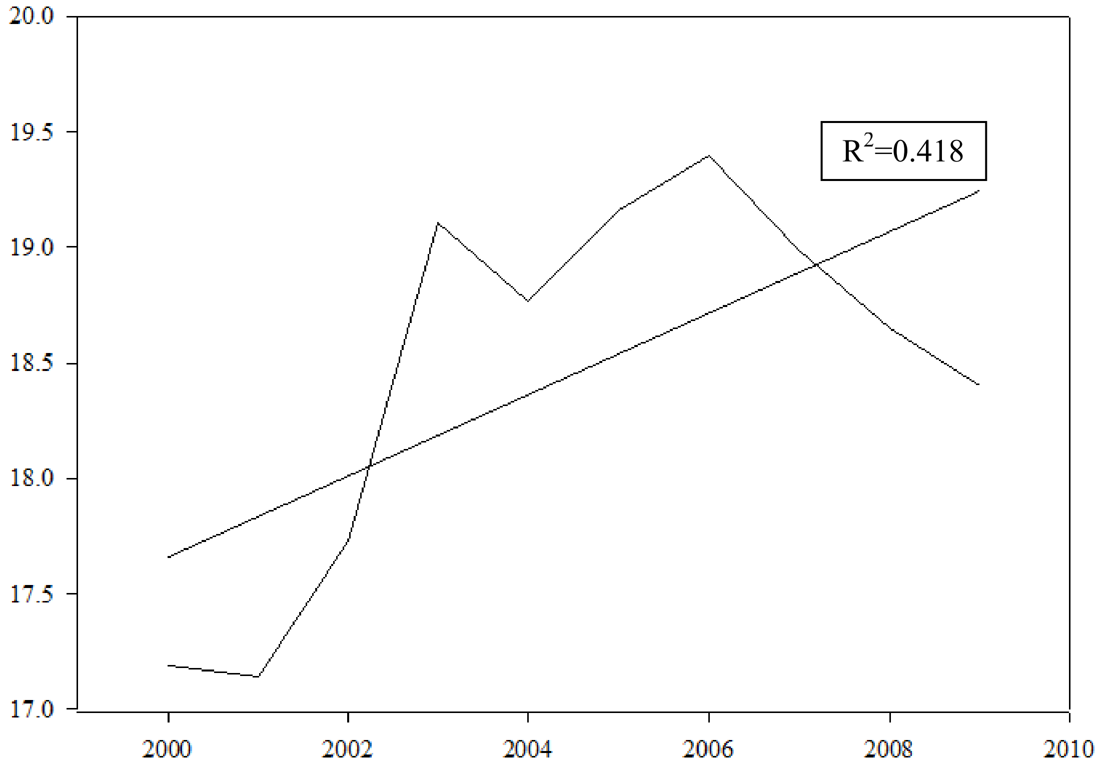


Figure 6.4. Trendline of maximum temperature (°C) in Sicuani between 2000 and 2008
Source: SENAMHI

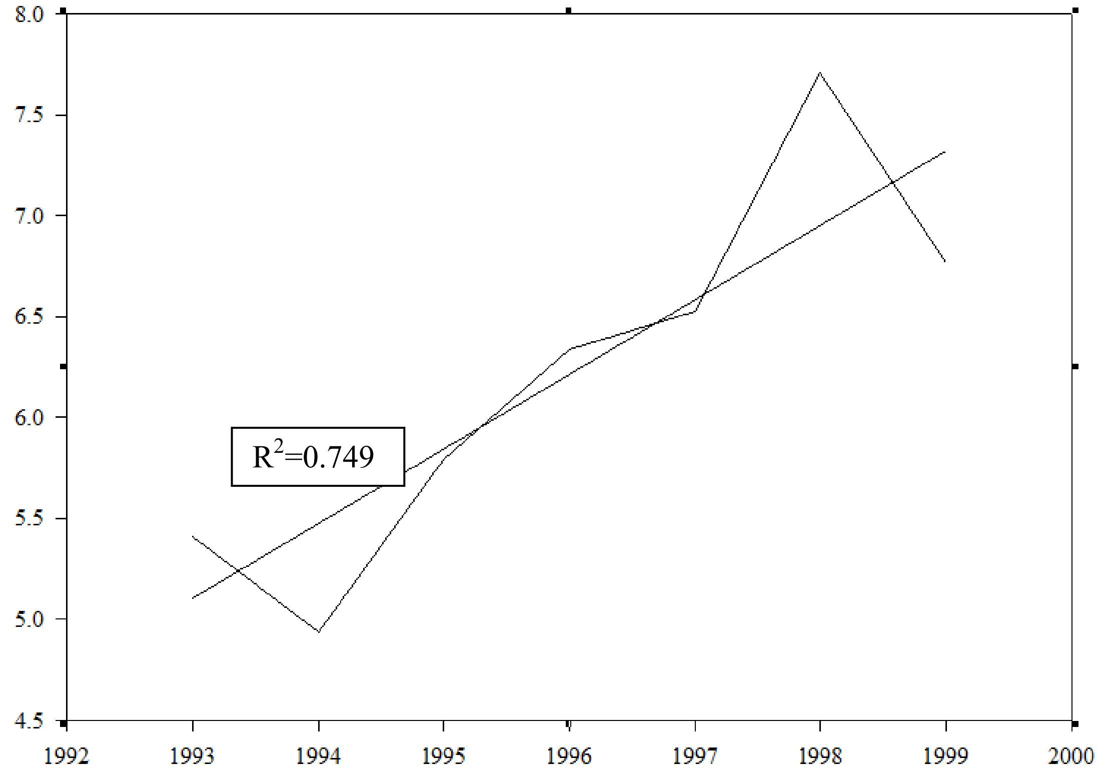


Figure 6.5. Trendline of minimum temperature (°C) in Sicuani (Cusco) between 1993 and 1999
Source: SENAMHI

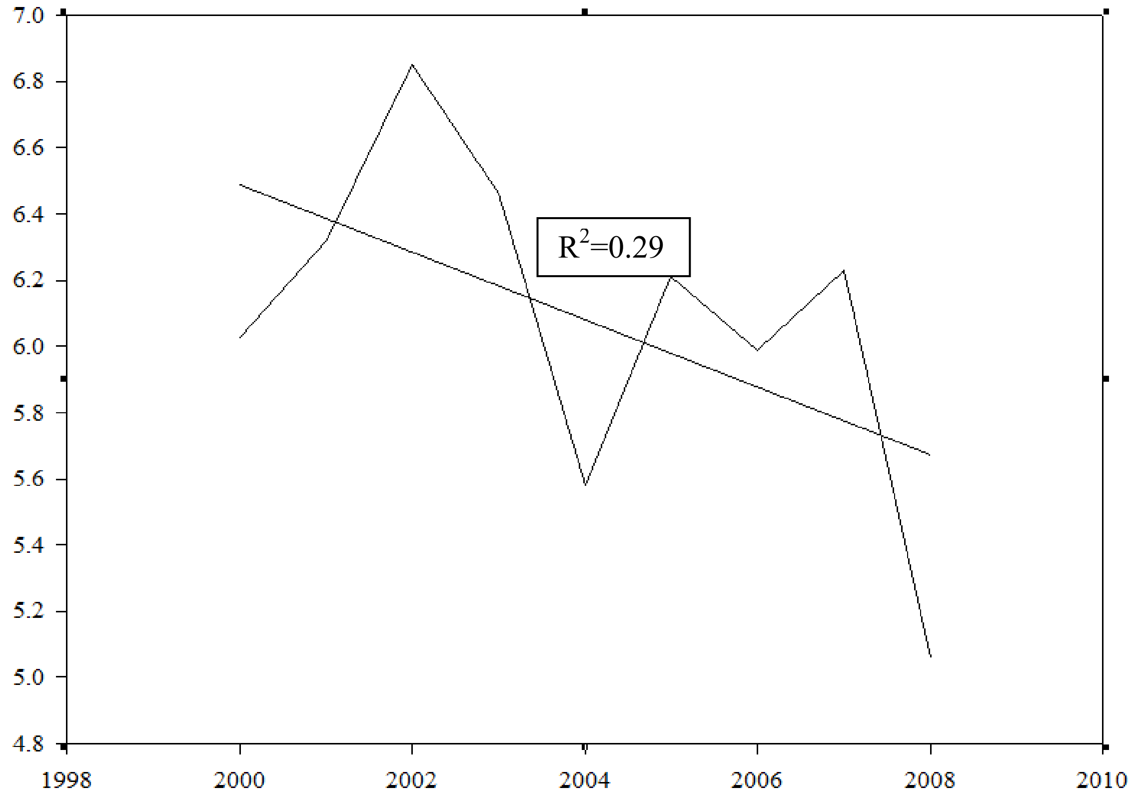


Figure 6.6. Trendline of minimum temperature (°C) in Sicuani (Cusco) between 2000 and 2008
Source: SENAMHI

Peasants' perceptions on changes in precipitation are consistent with finding of research on climate change in the Altiplano region, which using multi-scenario modeling, has projected increasing precipitation extremes, where the rainy season will intensify and start later in the year, and dry spells (during the rainy season) will be longer and more frequent (Thibeault, Seth, and Garcia 2010). Furthermore, Valdivia and colleagues (2010) analyzed the models employed in the Intergovernmental Panel on Climate Change (IPCC) using the Coupled Model Intercomparison Project (CMIP3) and projected that precipitation changes in the region will be: i) a drier and earlier rainy season (September–November); and ii) higher precipitation at the peak of the rainy season (January–March).

Higher temperatures could be driving increasing incidence of pests in the Andes (Dangles et al. 2008) and elsewhere (Sutherst et al. 2011), as well as changes in the distribution of species (Young 2009). Further, more intense heat and longer dry spells will desiccate pastures. These desiccated pastures are more easily uprooted by the winds (which are also blowing more strongly) leaving uncovered soils. Uncovered soils are more prone to land degradation.

REGIONAL GOVERNMENTS AND CLIMATE CHANGE: BETWEEN AN INCONVENIENT TRUTH AND POPULAR NEGLIGENCE

The environment as a light weight in the political arena

This section analyzes how regional authorities have addressed climate changes and events. The environment, as a theme, occupies a secondary position in the regional agenda and carries little political weight. The Regional Environmental Authority (ARMA by its Spanish acronym) of Arequipa was created because of the concern of a group of functionaries regarding climate change. However, the manager of ARMA said that "…al nivel intermedio, administrativo y logístico ARMA (Autoridad Regional Ambiental) no existe. Tenemos una estrategia para enfrentar el cambio climático pero no tenemos financiamiento para implementarla" "((…) we do not exist at the administrative, logistic and intermediate levels. Further, we have a strategy to face climate change but do not have funding to implement it").

In an effort of a more systematic inclusion of climate change within the Regional Government programs and across all its directorates, the Regional Government of Cusco has established the Operative Unit of Climate Change. One of the objectives is to make climate change a component of all managers' offices. In so doing climate change will be incorporated into all projects carried out by the Regional Government. The Operative

Unit of Climate Change is formed by representatives from 4 Regional Directorates and 2 from the International Aid sector. The latter expects that the Regional Government will disseminate and replicate successful responses to the effects of climate change. In so doing, the Regional Government aims to concentrate all the actions undertaken to cope with climate change and link the work of different sectors. This linkage will bring together the emergency relief work of the Central Government in the region, the contingency plans of the health sector, and the adaptive actions carried out by the Regional Directorate of Economic Development.

This unit uses scientific research to inform their decision making process and promotes a climate change working group formed by stakeholders from governmental agencies and the civil society, with the goal of developing the regional strategy to face climate change. Linking research to the decision-making process builds local capacity. Thus feasibility and sustainability of designed programs is assessed, prior to implementation, based on research results. The strategy of having all the different stakeholders participate will potentially create tensions between regional and local authorities, because each one has different agendas and political needs that come into play in the elaboration of the participatory budget that decides money allocation and expense priorities (Sabatini 2003). Additionally, this potential tension may hamper carrying out programs that cross over boundaries of different administrative units, such as districts, provinces, and regions.

In Puno, addressing climate change falls within the responsibility of the Regional Management of Natural Resources and Environment. More specifically, in the Sub-Management Office of Natural Resources, there is an office of Climate Change, Desertification and Water Resources. Though this office has only one person working in it currently, the goal, depending on budget, is to have a team of three professionals from natural and social sciences to tackle climate change in Puno. This Director admitted that:

> (…) el tema medio ambiental no está presente para el gobierno regional, consecuentemente, esta gerencia es considerada de segundo nivel porque no hace obras, por lo tanto su accionar no tiene impacto político ni es reconocido por la población u otros funcionarios del gobierno regional.
>
> (…) the environment is an absent theme in the Regional Government, therefore this Directorate is considered as second tier because it does not build new structures so its activities do not have political impact and are not acknowledged by the population or other functionaries in the Regional Government.

Though functionaries stated that Regional Governments are facing climate change based upon the hazards and risk-management perspective, hence planning before the events occur, their actions and projects indicated that their perspective is reactive to hazards and/or extreme weather events. For instance, regional governments have designed focused contingency and emergency plans by administrative units (e.g., agriculture, and health). Thus, the health sector understands that droughts do not kill but malnutrition does, so it is the agriculture sector, through irrigation, that must expand the agrarian frontier and increase yields preventing food shortage due to drought. Further, health functionaries aim to improve the good use that households make of food (for a definition of food security's pillars see: Barrett 2010) through workshops, lectures, home gardens, and diet diversification. These responses implied an understanding of environmental change as perturbations and stressors; therefore the understanding of vulnerability is limited to the exposure to such hazards (Adger 2006; Turner II et al. 2003). In this perspective, adaptation is reactive, and responses to climate change's effects are enacted only as they occur (and not proactively) (Wilbanks and Kates 2010). The focus on perturbations limits the assessment of change, since it misses the impacts on, thresholds of, and feedbacks from the system, thus overlooking systems' resilience and adaptive capacity (Adger 2006; Turner II et al. 2003).

The functionaries in charge of natural resources and environment have been focused on creating environmental norms and monitoring whether industries uphold such norms. However, functionaries have become aware of changes in the climate due to field reports about lowering lake levels and drying springs, which in turn trigger peasants' to demand access to water. For instance, Lake Titicaca's level has diminished 70 cm and its shoreline has contracted up to 1.5 Km. The authorities are not the only sector showing negligence. According to the Regional Manager of Natural Resources and Environment in Puno, awareness is linked with little budget and scarce knowledge:

> La consciencia del problema va aunada con el reconocimiento del poco presupuesto que el Gobierno Regional destina a las acciones para enfrentar el cambio climático, y de lo poco que se conoce del tema en la población, sobre todo la urbana cuya percepción está distorsionada porque hay lluvias. Es posible que esto cambie notablemente con la ocurrencia del Fenómeno del Niño y la consecuente sequía en el sur andino.
>
> Awareness of the problem [climate change] is joined by acknowledging the small budget the Regional Government channeled to actions facing climate change, and that little is known by the [local] population about the theme [climate change], and even less among the urban population, whose perception is distorted because there is rain. It is likely that this perception changes with el Niño (ENSO) and the consequent drought in the Peruvian Southern Andes.

The increasing awareness of environmental issues has not been matched by higher budget, extended research, improved human capital, and enhanced capacity. Regional authorities' negligence of environmental issues is reinforced by officers overwhelmed with unfunded new responsibilities stemming from the ongoing decentralization, distraction from budget battles with the central government, limited budget, scarce information and knowledge, and limited analytic capacity (Varillas 2010).

Agrarian Sector

The agriculture sector officials reported observing the impacts of climate change. The Regional Agrarian Director in Puno said: "(…) observamos que el calendario agrícola está alterado, la siembra se ha trasladado de octubre a noviembre; mientras que en las zonas altas el deshielo de los glaciares llevará a que las escorrentías cesen y con ello los bofedales se sequen" ("(…)we have observed that the agricultural calendar is altered, sowing season has moved from October to November; while in the highlands, glacier melting will cause runoffs to cease flowing, which in turn, will cause wetlands to dry"). In Arequipa, agrarian functionaries are dedicated to training and organizing farmers to benefit from the Free Trade Agreement with the USA, while climate change will be faced by: "(…) planes de contingencia contra El Niño, heladas y sequías, aunque no hay un documento específico para enfrentar el cambio climático" ("(…) contingency plans against ENSO, cold spells and droughts; and yet there is no specific document to face climate change").

In Puno, the Director of the Agrarian Promotion Directorate, though he acknowledged that climate change is a consequence of globalization, also admitted that they do not have plan or policy regarding climate change. However, the Director of the Regional Agrarian Directorate and his main functionaries said that "El cambio climático se enfoca desde la gestión de riesgos" ("Climate change is faced from the risk management perspective") and in order to do so they were prioritizing writing the contingency plan to face drought during the occurrence of El Niño Southern Oscillation (ENSO) (at the time of the interview). The National program 'Agro Rural' incorporates climate change through projects on pasture recovery and building shelters to protect livestock. The Arequipa office of Agro Rural, whose jurisdiction includes the departments of Tacna and Moquegua, had built (by 2009) 1,700 shelters and had planned to build 510 more.

The Agrarian Promotion Directorate in Arequipa is promoting change of crops in areas of water scarcity. For instance this Directorate is fostering the replacement of alfalfa by forage maize for cattle of the dairy industry, which implies a transformation of cattle feeding systems. This Directorate is also improving water infrastructure—i.e., reservoirs and channels—to diminish leakage. Furthermore, a pilot irrigation system has been implemented, which may be part of a large strategy of efficient water management. In 2008, the responses of this Directorate to cold fronts have been: 1) Grass cultivation (500 ha sown in 2008); 2) Technical assistance for grass cultivation; and 3) Provision of vitamins, antibiotics to 20% of the alpaca population of Arequipa. In 2009, it was proposed to expand grass cultivation to 1000 ha with a grass package composed by oat (120 kg/ha), barley (120 kg/ha), English rye grass (22 kg/ha), Italian rye grass (6 kg/ha), white clover (3 kg/ha) and red clover (3 kg/ha). According to estimates of the Agrarian Promotion Directorate in Arequipa, herders made pasture scarcity more acute by increasing the amount of animals to 1 South American Camelid per hectare.

The Agrarian Planning Directorate in Cusco issued Contingency/Emergency plans to cope with cold spells in 2009. The agrarian sector was declared to be in an emergency by the central government and transferred approximately US $ 300,000 (in 2009 US dollars). This fund aimed to mitigate effects of cold spells by providing antibiotics and vitamins to herders in the highlands of Cusco. Contingency plans in the agriculture sector aim to diminish after-the-event impacts from ENSO, nightly frosts, and droughts; however, there is no plan to address adaptation to climate change as an event or as a set of new conditions. Climate change effects may lead to land degradation that will impact agriculture and livestock husbandry, thereby compromising households' livelihoods.

Further, governmental lack of planning is coupled with households' absence of long-term vision, generating a destabilizing feedback.

Environmental issues do not have either particular appeal to regional governments nor are of much interest to local functionaries. In general, the regional governments perceive that actions taken to face environmental change will not render political gains because they do not include building infrastructure and even if infrastructure was built it would be in rural far away areas; therefore they do not impact the voters nor leave a permanent footprint to be remembered. Further, socio-environmental conflicts are noted as factors jeopardizing investment, hence threatening development (Bebbington and Bury 2009; Bebbington and Burneo 2008; Bridge 2004b). The low importance of environmental issues is consistent with the low levels of human capital (thereby the need for capacity building) that regional governments have to utilize while undertaking actions to face environmental change, and the little power that they have to solve social-environmental conflicts. This lack of power has been noticed by social movements, which usually demand the presence of the executive power members to solve social-environmental conflicts (Defensoría del Pueblo 2007).

SOCIAL-ENVIRONMENTAL IMPACTS

People whose livelihoods are dependent on mountain ecosystems are vulnerable to the changes wrought by climate change (Anderson, Marengo, et al. 2011; Varillas 2010; Bradley et al. 2006; Spehn, Liberman, and Körner 2006; Young and Lipton 2006; Messerli, Grosjean, and Vuille 1997). Colder nights and hotter days are negatively impacting agro-pastoral systems, as well as biodiversity in the Andes (Young 2009) In the Peruvian Southern Andes, herders, agriculturalists, farmers, and urban dwellers are vulnerable to nightly frost that inhibits crop growth, while intense heat in the day burns crops and dries pastures (Seth et al. 2010; Valdivia et al. 2010; FAO 2008; Bustamante Becerra 2006; Halloy et al. 2006).

Climate change is enhancing extreme weather and climate events (Trenberth et al. 2007; Easterling et al. 2000). In so doing, climate change has multiple, and mostly interconnected, impacts on mountains (IPCC 2007; Viviroli et al. 2007; Körner et al. 2005; Beniston 2003). Modified precipitation, temperature, and atmospheric humidity are melting glaciers, changing soil composition, and shifting vegetation altitudinal ranges (Nogués-Bravo et al. 2007; Rosenzweig et al. 2007; Scheneider et al. 2007; Messerli, Viviroli, and Weingartner 2004), thereby modifying (and sometimes compromising) mountain ecosystem functions and services (Mark et al. 2010; Vergara et al. 2007; Bradley et al. 2006). This sub-chapter shows the effects of changes in the water system and temperature on the rural livelihoods in the region.

Water system

Climate change impacts on the region are diverse and, sometimes, counterintuitive. Reports from herders in the region are contradictory. They indicate that some wetlands expand whereas others shrink; similarly, there are springs that dried up while others had reappeared. In the community Suyo (Canchis-Cusco) the peasants noticed that impacts of climate change are the diminished water flow used for flooding irrigation, the lowered level of lakes, and diminished runoff from springs. Glacier retreat is one of the most conspicuous impacts of climate change, which has led directly to increased glacier runoff due to ice melting, though this is a short-term impact that may be reversed when the melting stops. Impacts of glaciers' ablation on runoff and groundwater have also been shown for other parts of Peru (Young 2009; Alzérreca et al. 2006; Molinillo and Monasterio 2006; Postigo 2006; Spehn, Liberman, and Körner 2006).

In Puno, a group of wetlands has been selected to be part of projects on improvement, conservation, and valorization of wetland ecosystem functions. Climate change is one of the drivers of changes in wetlands. Furthermore, pastures and wetlands are shrinking and changing location, which is significant due to its importance for high Andean livestock husbandry and ecosystem functions (Spehn, Liberman, and Körner 2006). Though authorities seem to ignore the importance of high Andean pastures for both water conservation and carbon sequestration (Rosegrant, Cai, and Cline 2002), denying that irrigation disrupts underground runoff and aquifer recharge (Meinzen-Dick 2007; Boelens et al. 2002) and that it compromises pastures' ecological functions. The importance of pastures and wetlands as natural water storage systems located at basin headwaters is often overlooked. Furthermore, pastures and wetlands are key in livestock husbandry, thus water provision in the highlands is crucial for pastoralists' livelihoods. Highlands and lowlands, upper, middle and low basins are interconnected by biophysical characteristics, above and underground water flows, and social networks; thus there is a mutual dependency, which has to be represented in the institutional framework of resources governance. By using this framework, water management institutions may be better equipped to address potential conflicts due to water scarcity. Thus, the legitimacy of the governance body may increase as well as the likelihood of a more sustainable system.

The water board 'Chili no Regulado' (Arequipa) has 6200 users and the water tariff ranges from 2009 US $ 6.6 to 40 per cubic meter. The president of the board has observed lessened runoff from the springs, and some small springs (3 to 5 l/sec) have even collapsed. Although the president did not attribute the diminishment of springs to climate change, he knows that such diminishment hampers aquifer recharge. The manager of the water board stated that the springs' diminishment is due to water extraction by wells and the low cost of water. The members of the water board noticed that river flow has decreased, which in addition to a shortened rainy season render water for irrigation insufficient. Furthermore, early onset of the rainy season has provoked erosion, and stronger runoff.

Water availability is inversely related with tensions amongst users and the pressure that they will put on higher levels of organization (Red Muqui 2011). For instance, in Arequipa the prevalence of agriculture over herding means that the board grants priority to agriculture irrigation over pasture irrigation. As a result, irrigators of pastures are not allowed to use water from rivers and streams that will irrigate crop fields in the valleys. Access restrictions and water scarcity fuel conflicts in the region over the control of water sources (Prado 2011), and points to clashes between upstream and downstream residents (Alerta Perú 2011; Boelens et al. 2002; Gelles 2000), farmers and peasants, agriculturalists and pastoralists, farming culture and pastoralist culture, and between subsistence and market economies (Boelens et al. 2002; Levieil and Orlove 1990). Amongst commercial farmers, water conflicts are spurred by the water required in high-productivity agriculture. In turn, high-productivity agriculture is fostered by the need to generate profit that will enable farmers to pay their debts with the financial system. Improvements to the government of water systems will have to include conflict resolution mechanisms in order to prevent a positive feedback from conflict. In other words, by incorporating mechanisms to solve water conflicts the institutions of water governance will be strengthened and the system more stable (Aragón, Carilla, and Cristóbal 2006; Spehn, Liberman, and Körner 2006).

Drier conditions may increase the amount of pests. In the focus group with women in Cusco, they explained that drought exacerbates the presence of *rancha* (*Phytophthora infestans*), which attacks potatoes. Furthermore, dry spells have become longer; lasting up until crops reach maturation, which causes loss of production. Peasants in the region have also stated that the wind is blowing stronger, which in addition to drier conditions has bolstered fires. This pattern has been seen elsewhere in the Andes (sensu Gunderson and Holling 2002).

Changes in precipitation patterns are impacting productive systems in the region. These changes cause lower water levels in the reservoirs, which in turn jeopardize hydropower plant operations, and thus energy provision to cities and industries. In addition to lower reservoir' levels, the vulnerable agrarian productive systems are engendered by leaking irrigation infrastructure and insufficient water storage capacity. The modified precipitation patterns negatively impact agrarian productive resources like soil and livestock. For example, periods of more intense but irregular rainfall—i.e., interrupted by dry and warmer periods—degrade the soil, increase the likelihood of pests, and produce ponds of stagnant water that affect livestock health. These flaws in the system diminish available water and the capacity to control available water, leading to less frequent irrigation turns per farmer, which in turn raises pressure on the crops. Further, groundwater overdraft—driven by low cost of water—and diminished precipitation, hamper aquifer recharge. This lessened recharge is expressed in drying springs, which compromise pasture irrigation and water available for livestock, thereby jeopardizing the resilience of pastoralist system. Thus, the agrarian productive systems—i.e., farmers, peasants, and pastoralists—become more vulnerable to natural and social stressors, which also weakens the institutions that govern resource use. Further, the weakening of institutions constitutes positive feedback loops in (and lessens the resilience of) the productive system (Bustamante Becerra 2006; Molinillo and Monasterio 2006; Swinton and Quiroz 2003). For example, a weakened water board would be less able to regulate water use, and organize the maintenance of the irrigation infrastructure, hence enhancing the flaws of the system (See Fig. 6.7, where dotted lines are positive feedbacks and continuous lines are effects).

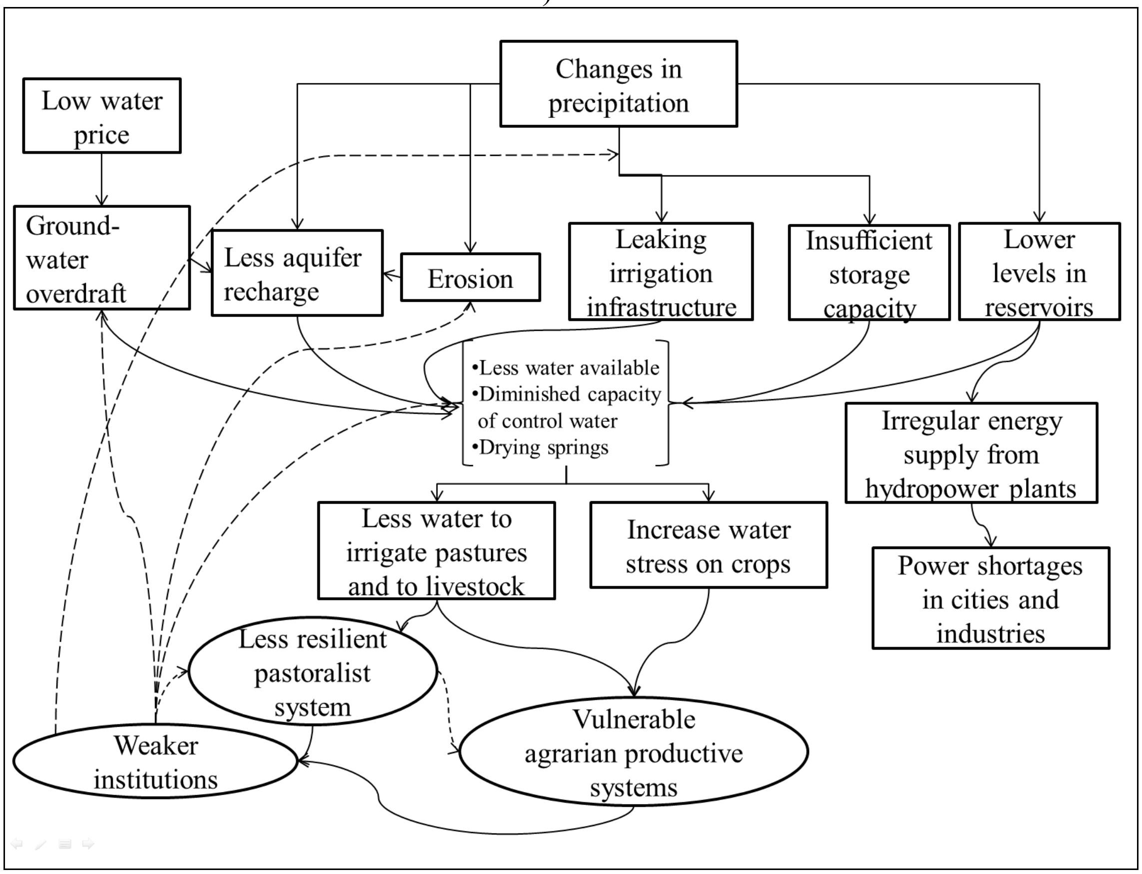


Figure 6.7. Effects and feedbacks in agrarian productive systems of the Peruvian Southern Andes

Temperature

The head of the Agrarian Promotion Directorate in Arequipa stated that “En las partes altas, la falta de lluvia y el incremento de la frecuencia de ocurrencia tanto de friajes como nevadas, han ocasionado la merma del tamaño de los pastos así como de la extensión de pastizales y bofedales” (“In the highlands, the lack of precipitation and the increased frequency of cold spells and snow falls, have diminished grass size as well as the extent of pastures and wetlands”)

Though the previous section showed impacts of precipitation changes on pests, rising temperatures may also be a driver of new pests. Peasants from the community Pampahuasi (Cusco) have perceived that new pests are attacking the crops. Furthermore, the peasants stated that rising temperatures may cause these new pests. In the focus group with women in Cusco, they reported that higher temperatures have increased diseases in animals and plants. In the community Yanque Hurin Saya, the peasants attributed the pest 'chocolate spot'—*Botrytis*—in broad beans to increased temperatures. This pest has led to increased pesticide use in summer; hence augmenting productive costs. A side effect of increased use of pesticide is that water pollution levels have also risen. In winter, the water demanded by vegetation lessens as do fumigation levels. Some herders consider that diminished humidity due to higher temperatures and scarce precipitation have increased the thickness of alpaca fiber.

Some interviewees stated that there are new pests in the wetlands and that they affect grazing livestock. It is possible that increased presence of mosquitoes is related to ponds of stagnant and warm water where mosquitos develop, later infecting the animals with various blood borne diseases. The altitudinal range of pests is expanding as they follow rising temperatures to higher elevations. Herders think that the incidence of pneumonia, blindness and mucosity in alpacas and coughing, swollen hearts, and death in sheep has increased due to the increasingly harsh climatic conditions.

In the community Urinsaya Llalla (Cusco) they indirectly related climate change with species extinction. The linkage starts with the fact that nightly frost freezes the crops after they had been irrigated. Asked about what they do to cope with nightly frosts, some peasants said "(…) después de la helada fumigamos la papa para que reaccione" "(…) after the nightly frost we fumigate the potatoes to make it react"), which prevents freezing. However, increased water pollution has decimated the frog population. Rats, on the contrary, seem to have increased as they thrive in the presence of stored crops (which the pastoralists are increasingly relying on). The crops in the valley floors are more exposed and sensitive to nightly frosts than crops on the slopes. This is because the slopes expose less area to the frost, there is less wind blowing, and are exposed longer to the sun. The longer exposure to the sun melts the frost faster; furthermore, the runoff from the melted frost clears fields on slopes faster than it does fields in valley bottoms.

Land degradation and desertification in the highlands are products of more frequent nightly frosts and a longer frost season as well as overgrazing (Vos and del Callejo 2010) and deforestation of native species in basin headwaters (Varillas 2010). In some areas, sheep are not allowed to graze because they foster land degradation through overgrazing, uprooting the pasture while grazing and kicking the grass when walking.

Low productivity and lost production compromises household livelihoods and food security, triggering migration to urban areas and to the Amazonia. Extreme cold temperatures have produced the unexpected impact of diminishing the number of irrigation turns per day, since frozen water during part of the morning delays the beginning of irrigation. This delay has prompted an institutional response in the form of a new irrigation schedule in the highlands of Arequipa. Delayed irrigation or rainfall has proven detrimental to crops because the asynchrony between water provision and crop needs (Vos and del Callejo 2010); for example, delayed rain falls when the maize is already dry, thus spoiling it. Maize is also affected by nightly frosts that burn its leaves. The yield of crops sensitive to low temperatures or water stress—e.g., maize, barley, alfalfa, wheat—have diminished-and in some cases-never regain their former productivity. On the contrary, new climatic conditions may be driving cultivation of vegetables in open fields of some areas where previous climatic conditions prevented agriculture (Young 2009). By the same token species may go extinct or have their potential distributions changed (Araujo 2008; Halloy et al. 2006). Some peasants have improved their productive systems with crops such as maize, broad beans, green peas, amaranth (*Amaranthus*), and sweet granadilla (*Passiflore ligularis*) whose altitude limits have shifted upward (Ertsen, Swiech, and Machicao Pererya 2010; Loayza 2006; Gelles 2000; Maos 1985).

SOLUTIONS, MISMATCHES AND SYNERGIES

Global environmental changes impact natural and social systems but also bring opportunities like crops shifting their ecological limits upward. The warming climate, shortened rainy season, longer dry and cold spells, are some climate change impacts in the Peruvian Southern Andes. These impacts jeopardize rural livelihoods, power generation, irrigation and drinking water supply; in so doing, attention is brought to efficient water use and water storage capacity to supply domestic water consumption and power generation. It is within the realm of impacts and opportunities that responses, from authorities and peasants, to climate change become complementary solutions or disastrous mismatches. There are also mismatches of expectations. For instance, interviewed peasants expect agrarian functionaries to promote agrarian development, provide technical advice *in situ*, and build infrastructure such as to shore up river banks, water channels, or water storage facilities. However, agrarian promotion functionaries reported that they are informing farmers and peasants about climate change consequences for the upper watersheds.

The region has also witnessed projects that increase inequality and fuel conflicts amongst peasants. For instance, a large irrigation infrastructure in Arequipa's valleys was developed to irrigate crops for exportation (Gelles 2000); however, it excluded herders in the highlands from use of the diverted water (Loayza 2006). In the Majes irrigation project (Arequipa), alfalfa cultivation has become dominant to be used as fodder for the cows that produce milk bought by the dairy industry. It currently uses more water than was planned during the irrigation's original design, causing an overuse of the infrastructure. The combination of misused infrastructure with a water demanding crop has lessened water availability and complicated water governance. The current way to allocate water is based upon plot size regardless of the crop planted. A foreseeable scenario of increasing water demand and diminishing provision may need accurate estimations of demand, which would be possible if each farmer declares what crops per area will be planted. Based on this information water allocation may be based concretely on the actual water available and crop needs. If a plan would be implemented one of its main components would be water management (Buytaert, Cuesta-Camacho, and Tobón 2011; Viviroli et al. 2007; Bradley et al. 2006; Messerli, Viviroli, and Weingartner 2004), which for the users would imply a reduced water provision. The users do not demand a plan, in part, because they do not yet see climate as a problem—i.e., they are not suffering severe, extended and constant effects of climate change. Under these conditions, it is unlikely that the users would be willing to diminish water demand, and it would be politically unpopular to reduce water provision.

Science-Policy interface

Global environmental changes are impacting water availability in mountain ecosystems (Celleri 2010; Buytaert et al. 2006; Messerli, Grosjean, and Vuille 1997). In the study region, the most pressing question is whether there will be enough water for the different uses required to sustain life. To answer this question basic research is needed addressing river flows, glacial contribution to stream discharge, above and underground flow connections, estimations of demand from different users, evaluation of infrastructure conditions, and modeling water supply with future scenarios. Results from research are critical to assess basin viability as well as basin capacity to satisfy users' demands (Quintero 2010; Vergara et al. 2007; Bradley et al. 2006). Research on the hydrologic cycle at the micro-basin level and on water availability will enable planning capacity to build infrastructure to store and allocate water, shift to crops that demand less water, and shift to alternative sources of power generation than hydropower (McPhaden, Zebiak, and Glantz 2006; Messerli, Grosjean, and Vuille 1997). For instance, infrastructure of different sizes is needed for human consumption, agriculture, and energy generation. Improvements in infrastructure should be complemented with a more efficient water use, which includes better irrigation technology and a more rational use of water in cities. Thus, infrastructure and users need to make progress towards better resource management in the context of acute climatic changes.

In Puno, the Manager of Natural Resources and Environment office in the Regional Government acknowledged in 2009 that his office is analyzing the water situation, in specific communities, as a response to communities' demands for water and alternative water sources. However, according to the manager, the studies needed should be undertaken by a research center, funded by the Central Government, wherein experts collect and analyze data, and elaborate policy proposals. The manager stated that a centralized research center would have more resources and capacity to recruit better professionals, more access to data and bibliography, and potentially more capacity to influence decision makers. Similarly, in Cusco, the Institute for Water Management and Environment (Instituto de Manejo de Agua y Medio Ambiente) an autonomous unit within the Regional Government, acknowledges the need for research on the effects of climate change on the environment.

Though there is a clear need for information and knowledge, research has to inform both the general public and authorities about climate change (Andrews, Stevens, and Wise 2002) and aim for policy changes (Adger et al. 2007; Cash et al. 2003; Turner II et al. 2003). Only then may policy makers outline research-based programs and strategies for climate change adaptation (Meinzen-Dick 2007; Cash et al. 2003). This is a big challenge for the science-policy interface (Bebbington and Bury 2009), and for the researchers to incorporate population and government concerns and needs (Meinzen-Dick 2007; McPhaden, Zebiak, and Glantz 2006; Cash et al. 2003; Messerli, Grosjean, and Vuille 1997). A potential contribution may come from some local governments that are incorporating climate change through economic and ecologic zoning whereby analyses of land use changes shed light on adaptive strategies to climate change. The need for research and knowledge may be addressed by a research center bridging science and policy design (Bebbington and Bury 2009; Cash et al. 2003; Clark et al. 2003), or implementing a research-action perspective (Baker et al. 2010; Messerli, Viviroli, and Weingartner 2004; Cash et al. 2003). The center's aim would need to be analyses of social and ecological impacts of ongoing environmental changes (e.g., impacts of warmer and drier climate), which will serve as foundation to elaborate policy recommendations and development programs (Rosegrant and Cline 2003). Increasing science-policy interactions contributes to the capacity for public officials, authorities and civil society to deal with the challenges presented by climate change (Sutherst et al. 2011; Fedoroff et al. 2010; Brown and Funk 2008; Lobell et al. 2008; Parry et al. 2004; Rosegrant, Cai, and Cline 2002).

In spite of the locally perceived impacts of climate change on crops shown in this chapter, the global debate about the scale of climate change impacts on crops has been hampered by the uncertainty in the models. However, the question of the planet's capacity to feed humankind, and particularly the poor, is undeniable (Valdivia et al. 2010; Cash et al. 2003; Rosegrant and Cline 2003). However, globalized agro-food system would tend to select a few varieties better suited for export for urban markets than to supply local markets. Farming systems may have to enhance their resilience to generate stabilizing feedback loops; for instance, crops more resistant to water stress, or with shorter growing periods may be incorporated into the system, while pressure for exporting may be balanced with food security needs. Prior to this incorporation, research has to develop crop varieties suitable for the new conditions, which points toward potential linkages among peasants, research centers, government agencies, and universities (Agrawal 2010; Adger et al. 2007; Turner II et al. 2003).

Social economic conditions and institutions are important determinants of a population's adaptive capacity and resilience to climate change (Valdivia et al. 2010). The poverty levels of peasant populations in the study region make them more vulnerable to acute climate variability and to more intense and extended extreme events (Ribot 2010; Valdivia et al. 2010; Adger et al. 2007; Agudelo et al. 2003; Alley et al. 2003; Swinton and Quiroz 2003). Programs to enhance adaptive capacity and resilience of the most vulnerable population have to be part of policies for poverty alleviation within a larger framework of sustainable and equitable development (Valdivia et al. 2010; Rhoades 2006).

A multi-actor and trans-scalar approach:

A better science-policy interface needs to be supported by empowered environmental authorities. Furthermore, isolated and marginal environmental functionaries will be incapable of tackling environmental change impacts on social-ecological systems. Solutions attuned to the magnitude of ongoing environmental change impacts may be obtained with a participatory multi-actor perspective (Engel, Pagiola, and Wunder 2008; for the Andean region see: Urteaga 2006; Press and Blach 2002). Though this perspective already exists in the Regional Environmental Commissions they need to be strengthened not only with funds and power but by making their agreements and norms legally binding. The Regional Environmental Commissions have been designed to address environmental issues with the participation of multiple stakeholders ranging from the government to civil society. In so doing, these Commissions have the potential to become a space to identify and foresee problems, design and debate solutions, and build a consensual proposal to tackle threats to the environment. However, the Commissions tackle environmental issues mostly from the perspective of managing environmental impacts caused by human activities; for instance current work on fire management in Cusco. Yet, environmental and climatic change impacts on human activities are mostly missed in the Commission work.

Market-oriented solutions for environmental problems are part of the political discourse (Urteaga Crovetto 2010; Bebbington and Bury 2009). Peru's Central Government has been attempting, since the early 1990s, to abolish community rights over water and land; thereby facilitating private investment and commodification of water and land (Rosegrant, Cai, and Cline 2002). In water management, market oriented solutions have included more expensive tariffs (Rosegrant and Binswanger 1994) and transferable water rights (Guevara Gil and Boelens 2010; Wunder, Engel, and Pagiola 2008; Dinar, Rosegrant, and Meinzen-Dick 1997), both with the premise of treating water as a commodity (for projects of payment for ecosystem services in the Andean countries see: Garzón 2010; Quintero 2010; Engel, Pagiola, and Wunder 2008; Wunder, Engel, and Pagiola 2008; Meinzen-Dick 2007). Whether this type of solution is feasible is beyond this dissertation's scope, though, the popularity of these solutions may be utilized as an opportunity to install the payment for ecosystem services approach (Baker et al. 2010; Rosegrant and Cline 2003), and to benefit from carbon sequestration projects (Engel, Pagiola, and Wunder 2008; Turner II et al. 2003; Press and Blach 2002). In so doing, providers and consumers of services are linked, which reinforces the need for multi-actor solutions for environmental problems (Baker et al. 2010), and fosters design projects to be funded by global funds to ameliorate greenhouse gas emissions (Celleri 2010; Quintero 2010; Alzérreca et al. 2006; Messerli, Grosjean, and Vuille 1997). By the same token, the highland landscape—i.e., wetlands, pastures— is crucial to water retention and aquifer recharge (Spehn, Liberman, and Körner 2006). Later, this water will be used further downslope in agricultural fields (Bradley et al. 2006; Buytaert et al. 2006) and cities (Bebbington and Bury 2009; Boelens et al. 2002; Hendriks 2002; Press and Blach 2002; Rosegrant, Cai, and Cline 2002).

Ecological and economic zoning have been recognized in the region as important mechanisms to regulate and organize land use. The design of the zones is a process by which the present and the future are confronted regarding population needs, and current and expected resource use. In Puno, there is a project of capacity building for territorial organization, which identifies ecological zones and environmental conflicts for water and land access. After the identification process a way of using the landscape is proposed. In Cusco, a representative of the Institute for Water Management and Environment suggested that climate change should be incorporated in the ecological and economic zoning processes; thereby climate change would be within some rural municipalities' tasks. For instance, the Network of Rural Municipalities included climate change as a theme in its 2009 annual conference.

Negotiating land use regulation is extremely political because it implies control over resources. Ecological zoning and land use/land cover change may be appropriate tools to understand ongoing changes on the landscape, and to design adaptive strategies that link climate change, desertification and drought. Implementation of the strategies will require synergic interactions between regional and local authorities, peasants, civil society, and international donors (Kendall and Chepstow-Lusty 2006). However, these negotiations require an institutional framework granting that all the stakeholders have equal conditions when negotiating. Lacking such a framework, tools with large potential for fair and sustainable decisions regarding land use, like zoning, may deepen inequality and perpetuate exclusion of marginal populations.

Regional governments, NGOs, and universities may combine resources and experience to implement integral programs focused on development in the highlands (Postigo 2010). These programs should have at least six main components: i) genetic improvement in alpacas to produce better fiber; ii) technical husbandry management; iii) herders' organization; iv) animal nutrition and veterinary skills; v) diversification of herders' economy to use alpaca skins and meat and; vi) commercial strategies and regulations preventing price control of the fiber price by textile oligopoly.

In Arequipa, the NGO Desco carries out projects of small-scale infrastructure to harvest and storage water (Postigo 2010). A group of NGOs has been providing small-scale technical advisory in water management and adaptive farming to current environmental conditions (Stadel 2008). In Cusco, the NGO Arariwa has been working in afforestation projects to improve micro-climatic conditions and water retention in the ground. The Swiss Agency for Development and Cooperation is carrying out a project to diminish vulnerability facing climate change through activities focused on water resources, food security, and risk management (Orlove 2009). Furthermore, also in Cusco, Practical Action develops projects addressing climate change, supporting native varieties of potatoes and improving animal health in the face of increased cold spells

(Orlove 2009). Following a community-based education approach (Andrews, Stevens, and Wise 2002) NGOs have been working based on information and on the community, with a participatory philosophy and an action orientation (Stadel 2008; Rhoades 2006; for the case of the NGO Agruco in Bolivia see: Rist 2000). This can be complemented by Regional Government programs: i) by scaling up successful NGO projects and, ii) improving infrastructure to irrigate and store water.

Local needs as opportunities to form complementary strategies

Peasants, farmers and authorities agreed, in the fieldwork, on the need of building and improving irrigation infrastructure; hence, this represents an opportunity to develop complementary approaches and engender synergies. In the light of complementary efforts and a better match between peasants' needs and actions implemented by the authorities, there are actions that the population across the region expects from the regional government to improve adaptation to climate change: 1) Create irrigation infrastructure: medium and small reservoirs, irrigation systems, wells, geomembrane pools, channels and water intakes, 2) Develop technical supervision of infrastructure works while the population contributes labor force and local materials, 3) Purchase machinery to make ditches, 4) Build greenhouses to develop tree seedlings of native species and shrubs, 5) Sow cultivated grasses, and produce hay and silage, 6) Improve commercial conditions for rural products, 7) Improve alpaca fiber quality, and 8) Strengthen water irrigation organization. For instance, the communities expect an expansion of the pilot projects carried out by the Project of Sub-sectorial Irrigation, which implemented modern irrigation systems—i.e., sprinkler and dripping—in peasants' plots in communities such as Lari and Cabanaconde in Arequipa.

Irrigation techniques and infrastructure have to become more efficient; for instance, moving from gravitational irrigation to drip irrigation, to agro-systems with crops that demand less water, and to less of a focus on cultivating maize and alfalfa to feed cows for the dairy industry. The built infrastructure needs to be complemented by capacity building to carry out better water management (Spehn, Liberman, and Körner 2006; Andrews, Stevens, and Wise 2002; Hendriks 2002). However, the Peruvian institutional frameworks for water and land management have increased national instability by excluding, through successive norms since the early 1990s, peasants and indigenous populations from access to water and land, due to the neoliberal reforms and structural adjustment policies (Urteaga Crovetto 2010) that were part of the globalization of the third world (Dunn 2009; Hveem and Nordhaug 2002; Kiggundu 2002). In addition, agrarian water use is the least regulated in Peru, and the water authority is within the agriculture sector, which suggests a conflict of interest, since individuals and groups outside of the agricultural sector are also dependent on water resources. Further, coordination with this sector in different regions has proven difficult. In some regions, agriculture functionaries have little legitimacy since they are perceived as not completing their expected work such as policy design, infrastructure building, and technical assistance.

Water management may be improved by small-scale water harvest techniques—e.g., ditches and mini-reservoirs in the upper and middle basin—and little reservoirs of geomembrane to store water for irrigation in the dry season, may be an opportunity to complement initiatives from peasants, authorities and NGOs (for a model of NGO intervention in a water system project see: Hendriks 2002). However, there is a need for monitoring because increased temperatures may cause swift evaporation of exposed stored water. To increase productivity though an environmentally sound approach, initiatives to fertilize fields with livestock dung are promoted by some NGOs and local governments. In other parts, water pumps may be a way to irrigate crops and to expand the agrarian frontier on dry land—e.g., Arequipa, Puno. In Yanque district (Arequipa) peasants demand assistance to improve agriculture by introduction of crops that are more resistant to water stress or rising temperatures. Water scarcity has triggered actions not only to improve water management but also to increase crop fields' productivity. Local-scale solutions have proven adaptive and have the potential to be replicated, modified and accepted in different contexts in the Peruvian Southern Andes (Valdivia et al. 2010; Orlove 2009; Stadel 2008) and elsewhere (Adger et al. 2007; Meinzen-Dick 2007).

Figure 6.8. Mismatch between peasants' need and government actions. On the left: water infrastructure wanted by peasants. On the right: infrastructure built by the government.

Though infrastructure to improve water availability is a shared need in the region as detected in the interviews, the infrastructure proposed has to consider the local needs and the available water to implement such improved infrastructure (*sensu* Alley et al. 2003; Hendriks 2002) (Fig. 6.8). It should be added that maintenance and repair of existing infrastructure is also a widespread need, to ameliorate water waste through leakage, water channels, broken gates, and blocked channels—e.g., by frozen water. Improved infrastructure will also speed up the water flow, so that not only will more water be delivered, but it will take less time to get from the inlet to the plot. In some areas infrastructure of different sizes is required to store water, whereas other parts need infrastructure to transfer water and, in others to irrigate and pump groundwater.

Another fertile terrain for complementary efforts is recovering vegetation cover through reforestation or cultivated grasses. Authorities and some NGOs provide seeds and materials to implement greenhouses to grow grass and seedlings of native and exotic species. Peasants could contribute labor, local materials, terrain for the greenhouse, and the area to plant the trees and grasses that will improve water retention and diminish runoff above ground. These techniques will alleviate rain-fed agro pastoral systems' water demands, ensuring growth of grass or crops in the dry season. There is also need of some infrastructure, like terraces, to prevent soil degradation due to intense precipitation. In higher elevation areas of Arequipa, the agrarian sector provided technical advice for and promoted grass cultivation (a combined package of oatmeal, rye, English and Italian rye grass and, white and red clover) to cope with pasture scarcity due to droughts and nightly frosts. However, production of cultivated grass should be complemented with making hay and silage infrastructure to store it. A cautionary note regarding cultivated grasses is that they can trigger a destabilizing cycle, which fosters livestock intensification that will demand more grass, which will increase water demand in a system with deficient infrastructure, inefficient water use, and insufficient capacity to adapt to climate change. Further, cultivated grasses need to be sown every year, creating a dependency of herders on the seed providers. They are also non-native species.

In the study region, some actions of the regional authorities have the goal of preventing or dealing with the effects of climate change. Vitamins and antibiotics for alpaca were provided to herders; more than 3000 shelters for livestock were built to help cope with freezing nights in Puno; in Cusco, there is an agrarian insurance that covers damage by ENSO or other natural disasters. It is well known in the region that climatic conditions affect viability of water and pastures, thereby impacting livestock health and nutritional intake. In the context of extended dry spells or longer periods of snowfall, regional actions intended to prevent pasture scarcity, help prevent livestock from becoming weak and vulnerable to disease from a lack of access to food.

Mismatches between peasant needs and government actions and unfulfilled promises are also at work. The mismatch exists in part because the population has very high expectations about what functionaries should be doing. For instance, it is expected that components of governmental interventions may be agrarian extension, technical support to replace long-cycle crops by short growing cycle crops—e.g., rye and barley—development of resilient systems and crops, recovery of vegetation, rural microfinance with low interest rates, and agrarian insurance. Additionally, information regarding the status of water and natural resources in an area would contribute to peasants' awareness of environmental conditions and constitute an input for planning and for community-based environmental education (Andrews, Stevens, and Wise 2002; Press and Blach 2002). Further, research suggests a territorial organization by basins rather than by political administrative units—i.e., departments (Dourojeanni 2000), and an approach of integrative water resources management (Bressers and Kuks 2004) that needs institutions that govern water basins. Climate change may be considered in economic ecological zoning as well as the territorial organization of the region. Programs in basins should include control of soil degradation and gullies. Furthermore, prescribed burning contributes to the prevention of wild fires due to intensified droughts and winds.

Local adaptive capacity and resilient systems

In the interviews, adaptive capacity enabled household and collective responses to climatic events. At the household level, peasants in the region generate smoke on the fields to prevent nightly frosts; to create the smoke, peasants burn scrubs, grass, and manure. To prevent hail storms peasants pay respect to mother Earth and the sacred mountains by detonating fireworks and little explosives. Peasants also use biological pesticide and ash against pests.

The collective responses are shown by actions carried out by communities and water organizations. An example of a communal response is the case of a communal institution that made land available in the lowlands, through communal work, for households whose land was affected in the highlands by climate change. Water organizations are challenged by increased water scarcity. For instance, in some areas of Arequipa, the traditional system of irrigation used to allocate water alternated turns between high and low community sectors. This system, however, was changed to allocate water based on a roster that starts with irrigators at higher elevation and from there moves to plots at lower elevations. This modification in water allocation was designed to improve efficient distribution of water. Irrigation institutions are adapting to changing climatic conditions. Further, organized water allocation and tariff collection have been shown in the Andes (Vos 2010; Gelles 2000). These activities heighten institutions' legitimacy, which allows them to consolidate their position within the system and bolster their role in adaptation. Hence, strengthening local organizations that manage water, with technical capacity to monitor infrastructure and consolidate management, may improve systems resilience in times of crisis (Rosegrant and Cline 2003; Hendriks 2002). Institutional arrangements in periods of change eliminate much of the pressure through solving conflicts, allocating scarce resources, and generating conditions for selforganization of the system (Postigo, Young, and Crews 2008; Meinzen-Dick 2007; Boelens et al. 2002).

Actions taken by peasants to cope with climatic events rely on knowledge of environmental and biological signals. These signals improve peasant's abilities to forecast the weather or seasonal changes. For example, if the Southern Cross constellation is descending in April it means, for the peasants, the onset of the nightly frost season. Southern winds indicate nightly frost while northern winds indicate rain. Biological indicators are also part of these signals; for instance, flowering of plum and apple trees in August indicates a good year to cultivate broad beans, and grass in the river in June-August signals a good year for agriculture. Animal behavior—e.g., certain birds in rivers or streams—are used to foresee how crops will do in the year. For instance, if *Vanellus chilensis—leque leque—*nests are at high elevation it means that it will be a rainy year, if the nest is at lower elevation, the year will be dry; by the same token, abundance of fish signals a productive year for agriculture. Other biological signals described in the interviews, were the presence of flamingos, fish jumping in the headwater of the basins, and eyes of cats changing to black color, meaning that it will be a good rainy year. Some of these signals are used also in the Titicaca region on the Bolivian side (Gonzales Iwanciw, Cusicanqui Giles, and Aparicio Effen 2005).

A local knowledge system is an active element of the peasants' adaptive capacity to environmental change. It is based on past experience but also interpreted in light of current events through new generations (Valdivia et al. 2010; Vos 2010; Bustamante Becerra 2006; Rhoades 2006; Erickson 1999). Elder members of the communities in the region are acknowledged as knowledge keepers; they identify and interpret signals in nature to elaborate climate forecast (Valdivia et al. 2010). The signals combine astronomic features such as position and brightness of constellations and the moon

(Orlove, Chiang, and Cane 2000), wind directions, and cloud shapes. In addition to local knowledge, social, human, and landscape capital are key components of adaptation at the local level (Agrawal 2010; Valdivia et al. 2010; Adger et al. 2007; Bebbington 1999; Blaikie and Brookfield 1987).

Though adaptation to climate change is carried out locally (Wilbanks and Kates 2010; Stadel 2008) national or international participation should not be ruled out. On the contrary, the magnitude of environmental change and the marginal condition of most vulnerable populations, urge synergic stakeholder multi-scalar adaptive responses (Young and Lipton 2006; Adger et al. 2003). Local solutions should complement solutions implemented by the authorities and civil society (Chapin III et al. 2006). Civil society expects that regional authorities lead the efforts facing the effects of climate change. In so doing, strategic alliances between regional governments, peasants, NGOs, and international donors may require institutional flexibility and equal conditions amongst stakeholders. These institutional adaptations may be strengthened with programs and projects of governmental and non-governmental agencies (Bebbington and Bury 2009; Rosegrant and Cline 2003), such as the pilot projects introducing drip irrigation and sprinklers promoted by regional functionaries. However, such complementarity is rare in the region because traditional responses are chiefly disregarded by regional functionaries, thus remaining an unrealized opportunity for synergistic process and responses between government and population.

Dynamic and troublesome peasant responses to climate change

Solutions in the peasant communities are not completely different than the ones implemented by the farmers, though the size and scale of infrastructure may differ. The interviews in the region showed that peasants, like farmers, want infrastructure to store water, and modern irrigation systems to irrigate pastures and crops. However, the land tenure system of small and dispersed holdings in the community hampers moving the irrigation equipment. Further, some communities are planning to convert pastures into alfalfa fields, and displace the alpacas that used to graze there to pastures located at higher elevations.

Agro-pastoralist communities combine herding animals in the pastures at high elevation with cultivating crops in the lower parts of the communities. The most important crops in the study region are potatoes, barley, maize, quinoa, wheat, and broad bean. Increased temperature has lowered crop tolerance to water stress. Responses to this climate change effect span from changing to cash crops with shorter growing periods and higher tolerance to water stress, to cultivating in furrows to cope with water scarcity. The furrows make water more manageable because they slow and direct the flow of water. Pastoralists herd mixed flocks of cattle, sheep, horses, and South American camelids. Extreme cold and hail storms affect livestock, shelters are needed to protect baby alpacas and in general, prevent the animals from sleeping on snow/hail covered soil.

Women explained in a focus group that they had modified the productive calendar in order to adjust agricultural tasks to changes in rainfall regime; they replaced maize for wheat and fava bean, because these crops are more resistant to cold spells. Another collective response identified during fieldwork was that communities have responded to nightly frosts by delaying the sowing season, thus avoiding freezing temperatures. The downside of this practice is twofold. First, the sowing season is concentrated in a short period of time, which implies a large demand of water that is not always available. Second, a shorter sowing season limits the seed growth period, yielding a smaller harvest.

In order to solve the problem of water availability, peasants want institutional solutions whereby better water management may be reached, including fair and rigorous water authorities that enforce norms, and irrigation turns for times when the water is flowing rather than when it is frozen. For instance, the institutional response in some communities was to rule that water access is granted only to whoever fulfills his/her duties—e.g., payment of water rate, or the completion of work in infrastructure maintenance. However, peasants acknowledged that trust has diminished, labor exchange to irrigate has faded, spurred by water scarcity, while irrigation turns and rules have failed, and norms of enforcement have weakened.

Pastoralist households have responded to modified grazing areas by increasing livestock mobility within their pastures, creating and expanding wetlands through irrigation, limiting the allocation of wetlands to new households, and some are cultivating grasses. Besides asking whether extending wetlands and pastures would match the needs for grazing areas, it is also worth asking whether the irrigation network would be able to irrigate drying pastures and wetlands. What will herders who lack wetlands and pastures do? How will communities accommodate the households with no pastures and wetlands? Increased demand for grazing areas will require institutional solutions, beyond irrigation infrastructure, to make grazing areas available for households and ameliorate the uneven allocation of resources fostered by climate change.

Institutional modifications also are needed in organizations that work with peasants (Hendriks 2002). For instance, though peasants in the region demand financial support, they expect loan programs to consider that they harvest only once a year and are highly vulnerable to climatic variability and market fluctuations. Further, they expect lenders to consider that peasants compete against commercial farmers from the valleys that practice intensive agriculture, with 2 or 3 harvests per year that gives them more income and resilience to face variability. Financial as well as governmental organizations may design systems and policies, respectively, to implement agrarian insurance that protects against natural disasters and climate variability effects (for the adaptation of the insurance industry to climate change see: Mills 2005). Agrarian insurance has been proven to diminish rural systems' vulnerability, enhancing their resilience (Adger et al. 2007).

The civil society

The president of the Regional Environmental Commission in Cusco perceives a weak governmental institution addressing climate change in the Peruvian Southern Andes. Several regional functionaries indicated during the fieldwork that Directorates of Environment and Natural Resources in the Regional Governments either have not included climate change in their plans, or just included it as hollow words lacking content and specific projects. Most of the Regional Governments' activities are fragmented; there is not an integrated cohesive plan to cope with climate change. The actions related to natural disasters, e.g., risk-management or emergency relief, have started to be associated with climate change, revealing a short-sighted perspective and a misconception of climate change as occurrences of discrete events rather than a directional change of conditions. The points where regional authorities encounter civil society have been, if any, isolated campaigns, small conferences, but not an institutionalized space where stakeholders elaborate proposals of environmental governance (the importance of institutions linking multiple levels for the sustainability of social-ecological systems (SES) has been highlighted, among others, by: Brondizio, Ostrom, and Young 2009).

Despite the lack of information (or because of it), urban interviewees perceived that they were far away from climate change effects, and that urban areas are less vulnerable than rural areas. Peasants and farmers in the region, on the contrary, are more aware of changing climatic conditions. It has been suggested that the greater awareness of climate change is due to the rural nature of their livelihoods and NGO projects (Stadel 2008; Kendall and Chepstow-Lusty 2006). The opinions of rural and urban populations, government functionaries and civil society, about climate change are derived from common sense, based on daily-life experience rather than upon scientific literature, and are rarely in agreement with the research community. Climate change impacts rural areas, which bestow food and water, and generate energy consumed in the cities; therefore, climate change is reshaping the urban-rural divide. The scale of these impacts is large, and to have a resilient productive system of food, energy and water will require multi-scale coordination and new relationships between urban and rural spaces.

Most of the NGO approaches and programs addressing climate change in Peru are still part of an opportunistic reaction to the flows of funding and to the mandates of international donors. These NGOs have not yet truly incorporated climate change into their programs nor have they developed a specialized human capacity to undertake this challenge (Orlove 2009; Postigo, Young, and Crews 2008). This is in sharp contrast to international NGOs who have become part of the climate change epistemic community (Gough and Simon 2001). Peruvian NGOs' efforts have hitherto included climatic variability impacts on farming systems but still within a productive paradigm rather than an understanding of the coupled human-environment impacted by sources of change (Stadel 2008).

CONCLUSIONS

In the Peruvian Southern Andes, the effects of climate change impact ecosystems and a mosaic of social formations along an altitudinal gradient. The impact is not harmonious or homogenous (Young 2009; Stadel 2008; Halloy et al. 2006). Further, as I showed in this chapter, the impact raises tensions as social formations battle for control of increasingly limited resources that are increasingly necessary to protect communities and individuals from bearing the full brunt of a changing climate.

The productive nature of water: 'The water has to be used so it is not wasted flowing into the ocean'

The utility of water is realized when it is put into a productive use—e.g., irrigation, human consumption, power generation. This is the productive character of water that transforms water from a nature's element into a resource. Consistently, water management aims to maximize water's productive uses with the least amount of water used. Though functionaries and peasants in the region expressed their concerns about the water available to satisfy their demands, all neglected the importance of water in the functioning of the riverine ecosystems and the services that these ecosystems provide. This partial and biased perspective on water overlooks its ecological functions, and how these functions are crucial to maintaining some productive conditions for agriculture and herding—e.g., soil formation, pasture maintenance—and the flow of water itself (Anderson, Encalada, et al. 2011; Celleri 2010; Quintero 2010; Alzérreca et al. 2006; Spehn, Liberman, and Körner 2006). The productive nature of water is embedded in the tensions among users for different levels of access and controls of the resource, hence the need for water management (Boelens et al. 2002).

It is understandable that the productive nature of water is the most important aspect of water for producers like farmers, peasants and herders. However, functionaries and NGOs would benefit by using the concept of environmental flow (Anderson, Encalada, et al. 2011). This inclusion would broaden their perspective to address water issues, provide a holistic approach through understanding ecosystem functions and their interactions with human water use. Finally authorities and functionaries would have a tool to assess the conditions of and potential threats to riverine ecosystems. Furthermore, to know the environmental flows in different rivers allows the flows to become goals for policy makers or indicators to be used by local users and stakeholders when water allocation is decided.

Under foreseeable water scarcity, access and control will foster conflict amongst water users as has already been observed in the confrontations between Arequipa and Cusco, and Arequipa and Moquegua. Climate change exacerbates scarcity, which will fuel tensions among actors. In so doing, water conflicts create room wherein other types of tensions and rivalries may be acted on. For instance, dormant old ethnic rivalries, regional prides, and racial differences may become active under a conflict over a resource. Scarcity and conflict reinforce the importance of an equitable multi-scale water governance scheme (Meinzen-Dick 2007), with stakeholders participating across different administrative levels. Further, the concept of environmental flow may be extremely useful as a tool of water management, more so in contexts of water scarcity or amidst conflicts for water. The concept aims to determine the flow regime needed to both preserve ecosystem functions as well as water provision for human use or storage, therefore non-productive functions of water are considered (Anderson, Encalada, et al. 2011; Tharme 2003).

Land use change has intensified resource exploitation and fostered land cover change in the Peruvian Southern Andes (Young 2008; Zimmerer 1999). Land use and land cover dynamics are driving accelerated loss of natural cover (Thornton and Herrero 2010; Young 2009; Polk, Young, and Crews-Meyer 2005), hindering the capacity of the ecosystems to store water (Spehn, Liberman, and Körner 2006). Upward shifts of the limits of productive zones bring opportunities for developing agriculture at higher elevations; however, at the same time, productive zones of livestock husbandry and pastures are displaced to even more marginal and higher areas (Young 2009). This displacement would jeopardize ecological functions—e.g., wetlands draw water and contain fossil carbon—fulfilled by pastures and wetlands (Buytaert, Cuesta-Camacho, and Tobón 2011; Alzérreca et al. 2006; Spehn, Liberman, and Körner 2006) that would be replaced by crops that require burning fossil fuels—e.g., irrigation or pesticides—to make them productive.

Climate change effects on social and ecological systems

Though climate change effects in the region compromise the productive systems of farmers and peasants, there are several other drivers of change, mostly of a social nature, trans-calar in scope, and of diverse temporal scale (Young 2008). In the region, the most common effects of climate change have been: i) shortened rainy season with intense rainfall interrupted by several dry days; ii) warmer days and colder nights; iii) glacier retreat; iv) diminished hail and snow fall; and vi) stronger winds. Peasants' livelihoods and food security have been threatened since environmental change has impacted crops, pastures and livestock, and increased land degradation (Young 2008; Swinton and Quiroz 2003; Reardon and Vosti 1995). Crops and pastures are facing more frequent disturbances, and more intense stressors; for instance the growing season is more unstable and pests are rising. The herds are under more pressure due to wetlands and pastures shrinking and springs drying, while highlands are more prone to fire. Further, grazing and fire often not only occur simultaneously but interact in complex ways (Spehn, Liberman, and Körner 2006). For instance, fire consumes biomass and determines what is left to herbivores, whereas grazing influences the frequency and intensity of fires (Aragón, Carilla, and Cristóbal 2006).

The adaptive strategies of the peasants are based on a flexible productive system that accesses and controls as many productive zones as possible, deploys multiple productive cycles, and diversifies livelihood sources (Vos 2010; Young 2008; Mayer 2002; Murra 2002; Zimmerer 1999). These strategies are only possible because the households live in a context of complex institutions that determine access to natural and social resources (Stadel 2008; Young and Lipton 2006; Mayer 2002; Golte 1980). For instance, adjustments in the agricultural calendar to changes in the rainy season are possible because there is a dynamic social organization and flexible institutions for water use, and access to land and labor. Furthermore, changes in the irrigation systems to allocate water more efficiently show an institutional adaptive response to an environmental change that led to water scarcity.

In the study region farmers and peasants interviewed were willing to incorporate new irrigation technology and water management techniques for a more sustainable and efficient use of water. Problems of technological adoption were related to poverty, which prevents buying and maintaining the equipment (sensu Rosegrant and Cline 2003; Swinton, Escobar, and Reardon 2003; Figueroa 1998). Besides this limitation, I believe that this openness to innovation is part of the flexible productive system of peasants and farmers in the region that takes all possible opportunities to face change and stress, as has also been shown by development interventions in the Himalayas (Clark et al. 2003). Moreover, in some parts of the study region, herders are fertilizing pastures with manure, sowing cultivated grasses, and maintaining dirt channels to diminish leaks. Combined interventions of governmental and non-governmental agencies providing technical assistance would complement and enhance the results of these technical adoptions as has been observed elsewhere (Clark et al. 2003; Rosegrant and Cline 2003). This will imply a major shift within the paradigms of Central and Regional governments.

Government at both levels must recover their former position as provider of technical support and agrarian extension, thereby leading innovation through crops more resistant to water stress and pests, and shorter growing cycles. Another role that is missing at present that governmental officials should play, is to promote participation in solutions by all stakeholders, which contributes to policy design, institutional governance , and adaptive capacity of the system.

The (dis)connection between central and regional authorities

The relationship between the Regional Governments and the Central Government in Peru is complex and contradictory. Relations between the regional and central government are not only issue-dependent but also associated with political affinities and alliances (Muñoz Chirinos 2008; Willis, Garman, and Haggard 1999; Véliz 1980). Decentralization aims to give more power, responsibilities and funds to the regions (Montero and Samuels 2004; O'Neill 2003); however, the process has proved challenging due to the unclear domains of each administrative level, battles over the control of resources and taxes, and clashes over the boundaries of power and authority (Ahmad and García-Escribano 2006; Sabatini 2003; Willis, Garman, and Haggard 1999).

Though decentralization may appear as a means to deploy more effective activities in the field (Iwami and Petchey 2002; World Bank 1997; Winkler 1989), it also breaks linkages between the capital and the regions, when regions are not necessarily ready to carry out their tasks. Further, decentralization implied that offices were transferred from the Central Government to the Regional Governments, so they changed from being part of the central authority to being part of an authority with limited funding and technical capacity that is disconnected from the central authority with its fiscal resources and technical competence (Varillas 2010; Willis, Garman, and Haggard 1999; Winkler 1989; Véliz 1980). In Arequipa, for instance, despite the creation of the Environmental Regional Authority to steer strategies addressing climate change, and degradation of air, soil and water, this authority has neither the power nor the funds to implement their strategies to face climate change. Furthermore, a new organization does not imply a new institutional culture, rather its work follows existing institutional inertia and continues to be dependent on the central government. Institutional autonomy requires willingness of the central government and political parties and the capacity of the regions to undertake their responsibilities (Sabatini 2003; Grindle 2000; Winkler 1989).

Summarizing: decentralization has proven challenging as an institutional framework to cope with climate change. There are, on one side, traditional structures that operate as a centripetal force that are withholding faculties from being turned over to regions (Ahmad and García-Escribano 2006; Willis, Garman, and Haggard 1999; Véliz 1980), thus hindering worthy programs to deal with climate change in the regions (Varillas 2010). On the other side, regional authorities are struggling to assemble qualified officials and teams with the technical competence needed to fully undertake their tasks (Varillas 2010; Montero and Samuels 2004; Rowland 2001). This struggle is an outcome of centralization, since the most qualified professionals are often concentrated in large cities. Adding a layer of complexity are the local authorities—i.e., mayors of provinces and districts who develop sets of vertical relationships with regional and central governments, as well as a horizontal relationships with other mayors (for the Bolivian case see: Varillas 2010; Montero and Samuels 2004; McNeish 2002; Rowland 2001); these linkages aim to obtain financial resources and power (Sabatini 2003). Further, regional and local authorities strive for political capital to act as an asset in their next political campaign.

Contested governance arrangements

In the region studied in this chapter, authorities, farmers, and peasants chiefly shared a misleading understanding of climate change as a discontinuous event whose effects are perturbations happening periodically. This understanding leads to reactive responses to climate change from regional governments. Yet, the understanding of climate change as a permanent change of living conditions has led to sparse and disarticulated projects; for instance, the pilot projects to improve irrigation systems. Further, peasants' responses are also somehow adaptive to changing conditions. These conditions require adaptive responses from natural and social systems. A crucial element to this type of response is adaptive capacity (Valdivia et al. 2010; Stadel 2008; Turner II et al. 2003), which in the region has been weakened by the decentralization process. Decentralizing has implied interrupted relations between technical teams in the capital and the regions, which has hampered their analytical capacity and diminished their competence in generating original and effective proposals.

The understanding of climate change impacts is partial and incomplete in the Peruvian Southern Andes; thus, an increased link between science and policy is needed to inform and design better policies to face current environmental change. These policies would enhance their impacts through synergic interactions with other interventions in the region such those of NGOs and local populations. NGOs have been implementing development projects for more than three decades in the region, while local populations have been responding to environmental change over millennia deploying strategies based upon local knowledge and dynamic social organizations. However, local social organization has been weakened by rampant poverty levels, and legal initiatives from the Central Government threatening communities' land rights to favor foreign investment since the early 1990s (Urteaga Crovetto 2010; Varillas 2010; Vos 2010). This confirms the trans-scale nature of institutional governance arrangements, and the Central Government's disregard of the key role played by communities in the sustainability of mountain systems, whose ecosystem services are crucial to the urban population and the agricultural production of Peru and the Andean countries (Celleri 2010; Garzón 2010; Quintero 2010; Varillas 2010; Vos 2010). Further, the Central Government's position towards communities was expressed by Peru's president in three grim articles (García 2008, 2007a, 2007b). He says that peasant communities and conservation NGOs are enemies of progress because they refuse to give up their right over land and water, and their lack of support for unmonitored extractive industries.

The Regional Directorates of agriculture have not formally incorporated climate change within their activities, based on the fieldwork conducted for this study. These directorates have had a productivity perspective that aims to increase yields, where climate is a group of contingent hazards that produce emergencies and disasters affecting production. However, it is clear that climate change will compromise the sustainability of systems, most noticeably, through water scarcity. As such, short-term efforts may aim to improve water through better infrastructure, efficient irrigation techniques, and legitimate institutions. Further, more intense and frequent temperature extremes are impacting crops, pasture, and livestock; thus there is a need for modeling the effects of changing temperatures on productive systems, which may be useful to stakeholders of rural livelihoods. Higher temperature also acts as a positive feedback to water scarcity through increased evaporation that diminishes the amount of water delivered to the plots, leading to an increment in the water demand of plants, in turn perceived as lessened precipitation by peasants (Quintero 2010; Valdivia et al. 2010). Increased evaporation, diminished and irregular precipitation, inefficient irrigation practices, and flaws in the system act independently or synergistically to bolster water scarcity in the region.

Peasant land governance institutions are dynamic and flexible. Institutions for water governance should follow the same principle, not only because of the flowing nature of water but more so considering that water systems may involve an array of actors from individual users to government agencies. Though there are cases of success and failure of water governance involving each one of these actors, successes were related to case-specific institutional arrangements. On the contrary, the failures mostly were transfer schemes considered as a single solution to all water problems (Varillas 2010; Meinzen-Dick 2007). The complex social-ecological mosaic of the Peruvian Southern Andes, in addition to the different type of water issues and the diverse local solutions to water shortages, requires multiple, flexible and adaptive institutions to govern water, that involve the relevant actors for the time and the scale of what needs to be governed. Though these institutions may be hampered by governmental initiatives (and the lack thereof), locally, institutions will have to face and work in a setting defined by warmer conditions and longer cold and dry spells coupled with increased rainfall variability, scarce infrastructure to store water, and inefficient irrigation systems.

Communal and regional adaptive institutions may be challenged because climate change and socio-economic forces engender vulnerabilities at multiple spatial and temporal scales (Adger, Arnell, and Tompkins 2005). Spatially, vulnerabilities range from local communities, regions and countries to the Earth's life-support system. The temporal scale of vulnerability spans from current conditions to scenarios that may occur from the short to the long-term. This spatial-temporal complexity confronts adaptive responses by asking who, where, when, and how to implement these responses and, more important lately, with whose money. Further, institutions, if they are adaptive themselves, may adjust responses based on multiple vulnerabilities. A possible path for adjustment may be building more complex institutions in which organizations operating at different levels may interact in a polycentric fashion (Ostrom 2009b; McGinnis 1999) but forming network governance (Jones, Hesterly, and Borgatti 1997) that enacts horizontal coordination amongst relevant stakeholders located at different levels (Papadopoulos 2003). Examples are government functionaries at the national, regional and local level, NGOs, peasants, farmers, and businesses. This polycentric network governance framework works as a task-oriented assemblage of organizations, which by design overcomes hierarchical-vertical-bureaucratic responses to disturbances. However, this framework may include mechanisms to assure egalitarian and democratic interactions amongst network members, otherwise the institution will favor the more powerful, vocal, and those with well-articulated proposals, who, more likely, will defend larger interests against less powerful and marginal social groups. In failing to follow this path in response to climate change may lead societies to face their limits to adaptation.

Chapter 7: Resilience and Adaptive Capacity of a High Andean Pastoralism Social-Ecological System (SES): The Quelcaya case

INTRODUCTION

Human-driven transformation of the biosphere is threatening Earth's life-support systems, creating an urgent need for a theoretical framework to understand sustainability of social-ecological systems (SESs) (Collins et al. 2011; Ostrom 2009a; Turner II, Lambin, and Reenberg 2007; Young et al. 2006; Clark and Dickson 2003). Several schemes for analyzing site-specific SES have been proposed (Chapin III et al. 2006; Rindfuss et al. 2004; Berkes, Colding, and Folke 2003) that aim to advance the understanding of sustainability and resilience. This concluding chapter contributes the case of a pastoralism SES in the high Andes of Peru. It also shows how distant drivers and proximate causes engender local changes in an SES.

The Quelcaya SES is composed by the pastoralist society and the *puna* ecosystem, which are linked through pastoralism. Thus, it is pastoralism, as a social activity, that creates this high Andean SES. Over centuries this SES has self-organized and has been resilient to changing social and environmental settings. However, recent multi-scale social and environmental changes are disturbing the Quelcaya SES, challenging its resilience and jeopardizing its sustainability. Though successful responses portray the adaptive governance paradigm, this case also requires i) poverty alleviation and improved living conditions, ii) synergies amongst the elements of resilience and adaptive capacity, and iii) transformability of the institutional framework of natural resource use. The interactions between global and local processes are asymmetric because the influence often operates from global to local and seldom otherwise. This chapter follows this pattern flowing from a discussion of the general and global arena to down to the local Quelcaya SES, wherein the dynamic impacts and responses are shown.

SOURCES OF CRISIS

Social and environmental variables are part of settings that both contextualize and influence the SES across spatial and temporal scales (Ostrom 2009a; Holling, Gunderson, and Peterson 2002) acting as exogenous controls (Chapin III et al. 2006). In the case of the Quelcaya SES (Fig. 7.1), as demonstrated in the Chapter 5 on Quelcaya's social system, the main variables of the social setting that affect local livelihoods are fourfold: 1) national policies, 2) mining, 3) fiber prices and the oligopoly of the textile industry, and 4) poor basic services. National policies of macroeconomic stabilization, a new mining code, and nondiscriminatory treatment were promulgated, during the early 1990s, to favor growing foreign/private investment, while other legislation has undermined communal property land rights and decision-making institutions (Urteaga Crovetto 2010; Bebbington and Bury 2009; Bebbington and Williams 2008; Damonte Valencia 2008; Bridge 2004b). Mining companies employ Quelcaya's herders, causing wage labor to compete with the non-market relations that support pastoralism. This may engender labor shortages (Zimmerer 1991b). The price of alpaca fiber is a source of vulnerability because it is the main commodity of the household economy and its price is internationally determined within a context of historically uneven terms of trade between pastoralists and the urban economy (Thorp and Bertram 1978). Further, the vulnerability is enhanced by the oligopoly of the textile industry, which controls the alpaca fiber's exportation and price. The textile industry controls the fiber price by being the main fiber buyer in the country. Education and health services are poor in Quelcaya hampering the development of human capital, which is an important factor of adaptive capacity. The variables of the social setting operate at multiple scales; however their direct impact is on the community and households, and through them on the ecosystem—e.g., leading to overgrazing and land degradation.

The variables of the environmental setting (Fig. 7.1), detailed in the Chapters 5 and 6 on local (Quelcaya's) and regional responses, respectively, to climate change, are changes in precipitation and temperature, glacier retreat, drought, freezing nights, ice/hail storms, all of which have become more intense and frequent under climate change (Seth et al. 2010; Valdivia et al. 2010; FAO 2008), diminishing ecosystem services (for the Andes see: Anderson, Marengo, et al. 2011; Quintero 2010), thus jeopardizing the SES's sustainability. The Quelccaya ice cap is located in the western border of the community. The retreat of the largest Quelccaya outlet has been ~10 times faster (~60 $m \cdot yr^{-1}$) between 1995 and 2005 than in the 1963 to 1978 period (~6 $m \cdot yr^{-1}$) (Thompson et al. 2006). The accelerated glacier retreat has increased the available water, which in turn is enlarging pasturelands. The latter process may bolster the amount of livestock at least temporarily; though this water increase is a short-term process that will last until the glacier edge reaches a new mass balance. Furthermore, drought limits water sources for livestock and vegetation; therefore, drought, as a negative feedback (for feedbacks in SES cf. Chapin III, Folke, and Kofinas 2009), may serve to stabilize overgrazing caused by larger amounts of livestock supported by the increased water from glacier melt. Freezing nights leave no grass for fodder, while ice/hail storms cover the grass preventing the animals from eating. Further, mining pollutes water and soils, and thus impacts the whole SES.

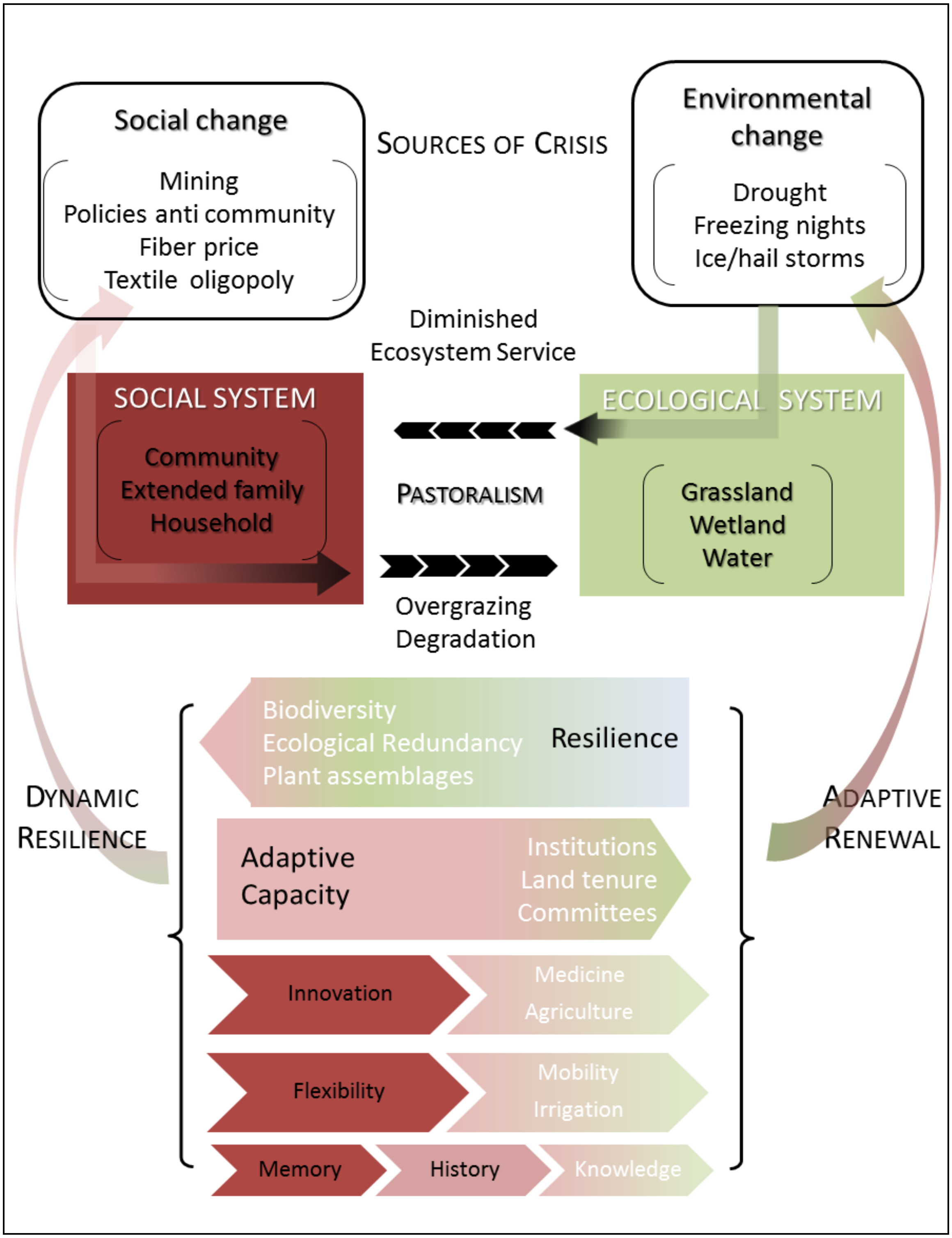


Figure 7.1. Quelcaya Social-Ecological System

SYSTEMS AND NESTED TIERS OF VARIABLES

The Quelcaya social system has four levels (Fig. 7.1). From the most to least inclusive these are: community, committees, extended families, and households. The community formally owns the land through a title to the territory and establishes institutions for communal resource use and tasks (e.g., Mayer 2002; Golte 1992; Mossbrucker 1990; Fonseca and Mayer 1988). The committees are *ad-hoc* institutions usually formed by elected community members to carry out specific tasks (Vos 2010). The extended families are groups of households that usufruct the land based upon consuetudinary rights, which have been transferred from generation to generation. The families also decide on household herding activities and allocate grazing areas among the households of the extended family. Though the household owns the livestock, it has different levels of autonomy regarding herding activities, which depend on the extended family's herding tradition, the household's position within the extended family, and the extended family's strategies for facing stressors and needs. For instance, the households' livestock may graze all together or separated by household; similarly, the grazing areas may be allocated following a rotation or a customary family rule.

The ecosystem encompasses ice caps, glacial valleys and the *Altiplano* plateau, as described in the study area (Chapter 2). This mosaic covers an altitudinal range from 4200 m up to 5700 m. The most prominent feature of the topography is the Quelccaya ice cap, which constitutes the headwaters of a glacial river flowing southeast through Quelcaya lands. Below the ice there are five glacier-dominated valleys and a plateau. The slopes are mostly covered by seasonal tropical alpine vegetation and grassland while the valley bottoms and flat areas are mostly conformed by wetlands (*Distichia muscoides*, *Eleocharis albibracteata*) with mosaics of cushion plants (Young et al. 2007). Water is a fundamental element to the ecosystems' functioning; it is provided by rainfall and melting glaciers, and the latter is crucial to sustaining water flow during the dry season (this has also been shown to be important for the Cordilleras Blanca and Real mountain ranges in Peru and Bolivia respectively) (Bradley et al. 2006; Mark, McKenzie, and Gomez 2005; Caballero et al. 2004; Francou et al. 1995). Vegetation absorbs moisture and slows above-the-ground runoff, easing water percolation. This water then flows by the aquifer downstream, where it resurfaces through springs. Climate change is stressing water availability through increased precipitation variability and intensified heat that raises evaporation. The links from water stress to pastoralism are twofold: livestock will have less water to drink, and the extent of wetlands and pastures will increase in some zones and diminish in others; thus fodder provision will be modified. This modification provides households with uneven access to fodder and will likely trigger tensions and conflicts among community members well as amongst communities. Further, these clashes may be solved through institutional arrangements to access, use and control land.

SUSTAINABILITY, INTERACTIONS AND OUTCOMES

Andean pastoralism has linked social and natural systems over millennia through social and biological processes: pastoralist society transformed and was transformed by its landscape. Chapter 1 showed that domestication of South American Camelids (Browman 1990; Wheeler Pires-Ferreira, Pires-Ferreira, and Kaulicke 1976) and adaptation to a high mountain environment (de Meer et al. 1993; Baker and Little 1976; Monge 1943) are likely the most long lasting coupled social-biological processes in the high Andes. These coupled processes have been resilient to major disruptions like the Spanish Conquest, which encompassed resettlement and depletion of native population (Cook and Lovell 1992; Schaedel 1992; Gade and Escobar 1982), ruined local administrative systems (Gade 1992), and introduced exotic crops and animals (Knapp

2007; Wheeler 1995; Brush 1976). In the high Andes, colonial livestock keeping and farming displaced native herders and herds to marginal lands at higher elevations (Knapp 2007; Bonavía 1996; Flores Ochoa 1982). These disruptions notwithstanding (and partially due to them), current herding of mixed flocks of alpaca, llama and sheep in pastures and wetlands is also an outcome of social-biological processes—e.g., Spanish conquest, livestock adaptation to high altitude ecosystem.

The Quelcaya pastoralists have lived in their territory for over 130 years (Fondo Tesorería Fiscal 1863). During these years they have defended their lands from surrounding landowners and other communities who have attempted to access and control Quelcaya's pastures. In so doing, the Quelcaya community has taken advantage of legal and administrative opportunities—e.g., norms that protected communities' land rights— resisted or, opportunistically, used government initiatives. Further, pastoralism is the main livelihood in Quelcaya and because of that, pastoralists and the landscape have changed and been changed by each other. In this mutual interaction, Quelcaya illustrates that resilience and adaptive renewal operate across several time spans thereby creating a sustainable SES.

High Andean pastoralism, as a social organization, has been entwined with domestication and colonial rule along millennia and centuries respectively, crafting dynamic institutions and developing an understanding of the landscape and environment. The "verticality" pattern of use of Andean space (Brush 1976; Murra 1967) expresses the understanding that Andean societies have had of their ecosystem. For instance, Andean social organization and knowledge have allowed productive zones, technology and development of tools (Mayer 2002; Golte 1980; Brush 1977), while institutions have allocated labor force, land and water among households (Postigo, Young, and Crews 2008; Young and Lipton 2006; Orlove 1982; Murra 1965).

Environmental change characterizes life in mountains. Ecosystem resilience and adaptive renewal have three major interweaving subunits: biodiversity, ecological redundancy, and plant assemblages (Hooper et al. 2005; Elmqvist et al. 2003; Loreau et al. 2001). These subunits are discussed in Chapter 4 about vegetation change on the forelands of the Quelccaya ice cap; the main findings are summarized as follows. The chronosequence and vegetation sampling found fifty two plant species in the area ranging from 4829 to 5113 m, which encompasses an area from the wetlands up until the lower border of four glacier edges of the Quelccaya ice cap. Along the altitudinal gradient, there are four plant assemblages. The species' upper limit is moving upwards, while species richness is skewed toward the lower half of altitude gradient. Low beta-diversity among the glacier outlets shows a trend towards vegetation homogenization with time (as was found in the Alps by Jurasinski and Kreyling 2007).

Distance from the glacier explains more variance in the patterns of species' distribution than elevation. The explanatory power of distance from glacier suggests the importance of ground conditions and soil formation to understanding vegetation establishment on newly uncovered soil at high altitude sites. This finding is consistent with research from other glaciers in the Andes (Schmidt et al. 2008). This also suggests that more research addressing how vegetation is influenced by coupled elevation-distance from glacier is warranted. The distribution of plant assemblages is that the wider the altitudinal distribution the higher the assemblage's upper limit is. Hence, assemblages are nested (see Fig. 4.3), although there are species with narrow altitudinal distribution in all the assemblages except for colonizers. The diverse ranges of species' altitudinal distributions implies differentiated rates of species' interactions across the altitudinal gradient, wherein species with wider elevation ranges will likely have higher rates of inter-species interactions than species with narrow ranges. By the same token species at higher elevations will take advantage of ice-free soil due to climatic change.

In the Southern Peruvian Andes, longer periods of drought are occurring more often at higher elevations (Llosa 2010; Seth et al. 2010; Valdivia et al. 2010), diminishing pasture for fodder. As shown in Chapter 5, Quelcaya's pastoralists are responding to droughts by enlarging and creating wetlands by irrigating pastures through dirt channels that are rebuilt each year depending on the location of the water source and of the pasture. Some of these channels are several kilometers long (Fig. 5.19), such that to build them requires cooperation and organization for the work. Appropriate social institutions are needed. Some households without access to irrigable pastures will lease pastures in the dry season from families that they had leased from in the past or to whom they consider have good quality pastures. Though a majority of the households does nothing to cope with the cold spells, actions to face droughts are very common. Such contradictory behavior may indicate the difficulty of coping with freezing nights and the confidence in the livestock's own resilience to survive freezing temperatures. The behavioral difference may also indicate that pastoralists face droughts using their social capital and social-ecological resources—i.e., channel building, which may not serve to cope with freezing nights. In fact, in these nights water freezes and does not flow in the channels. Further, increasing uncertainty regarding precipitation enhances the importance of rustic dirt channels to maintain pastures and wetland during the dry season, hence reinforcing the importance of social capital—i.e., cooperation to build channels—in adapting to change (for the importance of social capital in adaptation cf. Agrawal 2010; Adger 2003).

Social system resilience is due to its adaptive capacity, innovation, flexibility, and creative memory (Nelson, Adger, and Brown 2007; Folke, Colding, and Berkes 2003; Holling and Gunderson 2002). The adaptive capacity of the Quelcaya social system, as shown in Chapter 5, is expressed through its institutional flexibility, which is illustrated by observing the changing institutional arrangements throughout their history. A major institutional transformation occurred one hundred years after the Quelcaya families appeared in the contributors' book of 1863. In 1988, Quelcaya families became an official *campesino* (peasant) community in order to receive land redistributed by the government to peasant communities. By becoming a community the families gave up their rights over the land, whose property transferred to the community. This major institutional change in land tenure was guided by the practical reason gaining land. Though the community did not obtain any redistributed land because it submitted the documentation after the due date, the land tenure change rendered the Quelcaya's territory under a legal framework designed to protect community property rights.

Another example of institutional flexibility in Quelcaya is the formation of committees to undertake specific tasks. This change not only illustrates the use of institutions and organizations as a means to address issues or distribute responsibilities, but also is evidence of Quelcaya's institutional dynamism and vitality. In the past 20 years, the community has created an array of committees to undertake activities (Table 5.6), including vicuña shearing, communal house building, and the night-guard committee (*ronda*), originally created as communal protection against livestock rustling (for a description of Peruvian rondas see Starn 1999; Nuñez Palomino 1996). Quelcaya's *ronda* is a committee at the fifth nested level of the *rondas* organization. The fourth level is the district, the third the province, the second the department, and first overarching level is the macro South regional night-guard committee. Although the *ronda* is formed by community members and addresses issues within the community, it functions within the hierarchical levels, wherein district and units above have power over the sub-units. Meetings are held at each level to address issues that are beyond the jurisdiction of their sub-units; for instance, the province *ronda* committee meets to discuss provincial level issues as well as problems or cases that may happened in the districts or communities. Furthermore, decisions made at a higher level are carried out by the level below. The *ronda's* success against livestock rustling granted it legitimacy as a governance system and led to an increase in its functions to administer local justice—following their own system of norms and punishments—prosecute and condemn offenders of minor crimes (for rondas' institutional evolution in Peru cf. Starn 1999; Nuñez Palomino 1996).

Globally driven processes that disturb the Quelcaya SES are illustrated by alpaca fiber price and mining (Fig. 7.1). The commodity chain of alpaca fiber is likely the best example of an inter-scale variable because it links international markets with local alpaca herders. The alpaca fiber price has been a long-standing external source of vulnerability and uncertainty. The price is determined by the global market for the fiber and every component in the chain of production (from the global distributor to the local pastoralists) extracts its profit. Middle-men—working for the textile industry—set a fixed price to buy fiber in the communities or the nearest town, saving the transportation cost for the producer but limiting selling options and allowing only marginal profits to the pastoralists. The pastoralists are at the bottom of the chain, though they are the producers, and are paid the lowest possible price for their fiber; thus herders' vulnerability to surplus extraction and price control. The fiber passes through several intermediaries before it is used by the Peruvian textile industry, where the fiber is processed and transformed into yarn. Finally, the yarn is sold to textile manufacturers (generally abroad) to be weaved and commercialized. Global markets and firms control the fiber price; thereby affect the economy of the household. Further international markets decide whether fiber white or color is demanded, in so doing herd composition is led by fashion trends and market signals. Furthermore, in some areas, including Quelcaya, the Peruvian textile industry is paying a flat price for the alpaca fiber regardless of its quality. This commercial strategy discourages improvements of livestock management, which in turn, may diminish the quality of the livestock and enhance herders' vulnerability to the market.

Quelcaya's social system has been resilient through strategies that combine traditional ecological knowledge, use of multiple pastures, and dynamic social organization. The backdrop of these strategies is a cultural flexibility to incorporate innovations, which in turn redefine peoples' social memory to keep history present (McIntosh 2000). For instance, as shown in the Chapter 5, mobility has been a paramount characteristic of pastoralism, the seasonal grazing strategy aims to prevent overgrazing and degradation; it has also been a mechanism to cope with pastures covered by snow/hail or frozen, and to avoid having animals rest on areas with poor drainage. Further, in addition to livestock mobility, herders have been incorporating veterinarian knowledge such as giving medicine—e.g., antibiotics and vitamins—to the livestock to improve their health and ability to cope with harsh climatic conditions. Some elements of technical herding are been incorporated as well, to improve fiber quality and yield.

Pastoralists have diversified their herds forming a mixed flock of alpaca, llama and sheep. This alleviates pressure on the pasture because each one of these species prefers different plants and areas to graze (McGregor 2002; Bryant, Florez, and Pfister 1989; Pfister et al. 1989). Further, this diversification diminishes the vulnerability of depending on only one animal species for sustenance. Llama and sheep have different functions, the former is a beast of burden, and the latter provides wool, meat, and serves as a living savings account. Llamas allow the household to undertake long-distance caravans to barter pastoralists' products for maize and potatoes. Though challenged by the development of new networks of roads, caravans are a key element in household economy. Caravans provide mobility and choice in markets for selling or bartering products, thereby, sheltering households from price dynamics and uneven terms of trade (Tripcevich 2010; Ricard Lanata and Valdivia Corrales 2009; Inamura 1986). Further, bartering provides a better rate than cash sale, while it occurs amidst an institutional framework crafted by ceremonial kinship relations and long-standing barter exchanges (Orlove 1986).

Mining activity is another cross-scale variable that disturbs Quelcaya's SES. At the global level, it depends on international shareholders and dynamics of mineral markets. At the national level, the institutional and legal framework attracts investors and eases their activities (Bebbington and Bury 2009; Bridge 2004b; Naito, Remy, and Williams 2001) and weakens the rights of indigenous and local populations to control their land, water and resources both above- and belowground (Downey and Strife 2010; Urteaga Crovetto 2010; Warhurst and Bridge 1997). At the sub-national level, authorities are increasingly dependent on the tax transfer arrangement, in which 50% of mining taxes return to the regions where the mines operate (Bebbington and Bury 2009; Monge and Paz 2006). In the local SES, mining is a source of income (to workers and the community), pollution, and tension. Unevenly distributed income may lead to social differentiation within the community; however, the community created a work roster to prevent such differentiation, money concentration, and constant withdrawal of the same labor force from herding activities.

The presence of mining has affected Quelcaya. During fieldwork in 2008 and 2009, there were rising tensions between households and the community, and the young and older generations, regarding the mine's presence, resource use and benefits. Elderly community members tend to see the mine as a threat while young members see opportunities for wage labor in mining activities. Though the community controls and distributes the benefits of the mines—i.e., mines pay the community to operate on their land and they pay the fines for unfulfilled agreements. This engenders what I call a 'tragedy of the privates', which is an inverted version of Hardin's (1968) 'tragedy of the commons'. In this new tragedy, the mine directly works and impacts on some households' lands and not on the whole community—without considering externalities; however, the benefits of mining are mostly shared by the community. This 'tragedy' is raising issues about the land tenure regime and the mechanisms to allocate mine's payments amongst households. Further, local authorities are targets of pressures to favor mines operations, weakening the functioning of the community and the decision-making institutions.

The relations between community and mining include stable mid-term agreements and opportunistic short-term requests. The former mostly encompass contracts to use community's lands. The latter cover a range from money and machinery, to soccer games organized by the mine to develop camaraderie amongst workers and community members. The mine-community relationship includes negotiating areas where the mine can undertake activities and what the compensations would be for working in such areas, and granting favors upon community's request such as transportation in the mines' vehicles. However, uneven power relations operate in favor of mining firms as they are supported by capital, technology, political connections, legal framework, and governmental consent (Damonte Valencia 2008; for the case of households of herders and mining in Ancahs cf. Salas Carreño 2008).

CROSS SCALE TRAJECTORIES AND AGENTS OF DIRECTIONAL CHANGE

Social and environmental changes challenge the dynamic sustainability of Quelcaya's SES, potentially leading it to a regime shift from pastoralism to mining; thereby affecting ecological properties of the water and soil, while also converting pastoralists into workers. For instance, pastoralism relies on a cyclic dynamism of pastures, water and livestock that has to be sustained, whereas mining needs to extract as much mineral—i.e., non-renewable—in the least amount of time with little concern about sustaining the ecosystem. This potential regime shift would imply also the transition from subsistence to a market economy, wherein the community's land tenure regime will turn into mining's private property of the land. Money would become the dominant mean of social relations rather than the kinship and reciprocity commonly used amongst herders (Postigo, Young, and Crews 2008; Orlove 1986). Quelcaya's adaptive responses to increasingly faster and more extreme climatic changes may be weakened by mining since it compromises the availability of labor force, clean water, and land. Further, the lack of these responses—i.e., irrigating (with clean water) to maintain or generate wetlands, moving livestock to available grazing areas—threatens the resilience of pasture and water resource system, and jeopardizes ecosystem functions.

Though policy for sustainability of SES's has lacked opportunity, private investors have experienced favorable policies since the early 1990s in Peru (Urteaga Crovetto 2010; Damonte Valencia 2008; Durand 2005) and elsewhere (Bridge 2004a). These policies have been promoted, amongst policy makers, by policy entrepreneurs who have constantly developed investors' economic interests either around policies or enduring their benefits from such policies (Grindle 2001). The natural resource governance system is also weakened because its subsystems, operating at multiple levels, do not share a vision and instead have opposing goals and deploy counteracting measures preventing flexibility to cope with abrupt change. National and pro-rural livelihoods governance of natural resources is hampered because the Peruvian economy is based upon exports (Crabtree 2002; Klarén 2000; Thorp and Bertram 1978). Further, worldwide economic policies are designed under the paradigm of linear dynamics and single equilibriums

(Arthur 1999) and aim to control selected ecosystems to produce commodities needed in the economic system (Holling and Meffe 1996).

Multi-scale adaptive governance that builds social capacity for resilience (Adger and Jordan 2009; Folke, Colding, and Berkes 2003) seems urgent for Peru; however, it is hampered by the lack of a problem-driven window for policy design. There is no opportunity for such design because decision makers do not perceive this problem as pressing. Furthermore, tipping-point leadership (Kim and Mauborgne 2003) in environmental issues has been intermittent and weak in the country (Bebbington and Bury 2009). For instance, there was not a Ministry of Environment in Peru before 2009, but it was the Ministry of Energy and Mines that bear the responsibilities of promoting mining and monitoring its social and environmental impacts, as well as approving Environmental Impact Assessments of the mining companies; engendering an evident conflict of interests (Bebbington and Bury 2009).

Global drivers of change like climate and economic forces, acting locally, are pushing systems' resilience worldwide, and possibly, leading some systems to new states (Chapin III et al. 2006; Folke, Colding, and Berkes 2003; Lambin, Geist, and Lepers 2003; Gunderson and Holling 2002). In so doing, it fosters clashes of land uses and of the human-environment relations that support them (Lambin and Meyfroidt 2011). It also increases the tensions and competition amongst users (Rindfuss et al. 2004). Government, economic forces, and local populations have views and agendas about the SES that are almost fully incompatible, thereby raising issues in the political and political economy arenas, as well as in the institutional framework for natural resource governance (Bebbington and Bury 2009; Holling, Gunderson, and Ludwigh 2002).

Modifying the link between social and ecological systems changes the nature of the SES and alters local relations such as familiarity, reciprocity and trust, which are crucial for the generation of social capital and adaptive capacity (Adger 2003; Ostrom 1990). At the country level, mining's long-term endeavor in Peru (Postigo 2010; Elliott 2007; Lockhart and Schwartz 1983; Thorp and Bertram 1978) has undermined the local governance system and cultural integrity (Dell 2010). The most recent mining expansion is larger in scale, more diverse in terms of the types of minerals extracted (Damonte Valencia 2008), and combined with urban development fosters rural-to-urban migration. The increased scale and presence of current extractive operations constitutes a major source of potential pollution of land and water than prior mining, which was concentrated during colonial times on gold, mercury and silver in the Central Peruvian Andes (Nriagu 1994; Fisher 1977). The recent mining expansion has also involved the government's increasingly relinquishing the local population's property rights to land and water, and of international law to protect indigenous rights (Bridge 2004b). These processes further challenge the efficacy of local social capital and, thus, local sustainability and adaptive capacity to face climatic changes.

STEPS TO SUSTAINABILITY: A MODE OF CONCLUSION

Poverty and marginalization hamper the adaptation of any human group, more so in the case of a group of exclusive pastoralists—i.e., without agriculture—living above 4000 m under harsh climatic conditions. Improving public services like education and health with infrastructure, equipment, and professionals would enhance local human capital. Housing conditions need to be improved through a government (or NGO) program which will provide better health conditions and lower the incidence of respiratory diseases.

In the chapter on Quelcaya's social system (Chapter 5), it was shown how pastoralists face the risks of fiber production and obtain the lowest share of the ultimate profit, whereas middle-men, the oligopoly of textile and transnational firms avoid the risks associated with production and obtain a larger share of the profits. Furthermore, interactions with the market economy do not promote the improvement of livestock management in Quelcaya, on the contrary, these interactions seem to punish the herders that have better fiber quality by paying a flat fiber price. In 2009 fiber price plummeted, the Central government implemented a program to buy fiber at a higher price than the price pay by the textile industry, store the fiber until price raise again or transform it into yarn. In Puno the program aimed to benefit 150,000 herders (Los Andes 2009), which is an example of a government intervention to assist herders, rather than contribute to their sustainable development. Governmental roles may be enhanced in order to deploy a more inclusive economic policy to equally share risk and profit among stakeholders of the alpaca fiber productive chain.

Weakening communal institutions and rights over land increases herders' vulnerability to social and environmental change. The institutional framework that favors private investors' exploitation of natural resources and weakens community institutions may need to be revised to secure land rights of the communities. Though the National government has relinquished its regulatory role as part of the neoliberal reforms (Urteaga Crovetto 2010; Bridge 2004b), revising the quasi-universal divided regime of surface and subsurface property rights may be a key component of any effort addressing the legal framework of access to natural resources. Further, the institutional architecture of environmental governance has created environmental authorities typically powerless to enforce the law. In addition, the regulation and monitoring of the use of key resources like water and land are vested with each productive sector in Peru, reinforcing the tendency for overuse or misuse (Bebbington and Bury 2009).

Synergies between gradual and abrupt change are challenging the Quelcaya SES. Changes are driven not only by underlying and proximate social, political and ecological processes but also by legacies—events from the past that influence actual SES dynamics (Chapin III, Folke, and Kofinas 2009). Further, herder agency, which depends on legacies and goals for the future, shapes and is shaped by change. These interactions may lead to uncertain system dynamics. This uncertainty includes regime shifts if the system is unable to adapt; however, research is needed to assess the thresholds of the system. Droughts and cold spells are expected to be more frequent, last longer and have greater intensity, whereas the resilience of Quelcaya SES has been diminished by exogenous and endogenous human action. Multi-scale policy strategies to enhance the resilience and adaptive capacity of the Quelcaya SES are needed. Further, linking scientific knowledge with local knowledge will increase understanding of ongoing processes of change and the likelihood of developing adaptive strategies. The linkage of knowledge and policy would require that the government regain its role of promoting rural development, restating agrarian extension and technical diffusion of opportunities derived from change. For instance, local responses—e.g., irrigation of pastures and wetlands—that have proven to be effective stabilizing feedback mechanisms may be replicated by programs of the Regional governments. Regional authorities and non-governmental organizations (NGOs) should provide financial and technical support in building small-medium scale reservoirs and water storage systems for the dry season. Fodder production is critical to sustaining livestock, thus, applied research to develop cultivated grass and irrigation systems, as well an investment in silos to ensile grass will enhance the resilience of the productive system. Diversifying the livestock production to meat and hide products will diminish dependency on fiber. Further, NGOs and local authorities could train pastoralists to undertake these new activities following technical standards, while the Regional and

Local governments could promote high Andean products such alpaca meat in urban markets.

A potential trajectory towards a sustainable Quelcaya SES may be a better science-policy interface through bridging organizations (Gunderson, Holling, and Light 1995). Despite the absence of such organizations for Quelcaya, scientific teams have been a long-term presence understanding climate change through glacier dynamics in the largest tropical glacier of the world since early 1960s (Thompson et al. 2006; Mark et al. 2002; Thompson, Mosley-Thompson, and Morales Arnao 1984; Hastenrath and Koci 1981; Thompson, Hastenrath, and Morales Arnao 1979). It may be the case that scientists and science need to be more flexible, expand and adapt their roles to times of critical change, walking—more often—beyond the ivory tower and bridging to policy makers and stakeholders with the goal of creating a sustainable and equitable multi-scale world. This dissertation is a scientific endeavor whose output may be used to motivate stakeholders' involvement in dialogue and debate towards sustainable development.

The SES approach used in this research is an element of such a scientific perspective needed in times of change, since it allows an understanding of dynamic complex systems functioning across multiple spatial-temporal scales. For instance, global processes such as mining and environmental change in Quelcaya are examined from the macro level down to the local level. In the SES approach, change is both an exterior and internal forcing; the former acts as stressors or disturbances, while the latter constitutes a crucial characteristic of the system's adaptation and resilience. Outside change pushes the system to a different state, while the internal change aims to keep the system within its current regime; change is itself and its negation.

Appendix 1: Encuesta de hogar

01: Id. Entrevistado__________, Fecha____________, Hora________,

Encuestador____________

02: Datos Del Hogar: Sector_______________

Nombre de los miembros del hogar.	**Relación con el jefe del hogar**	**Edad**	**Sexo**	**Nivel Educativo**

¿Tiene familiares viviendo fuera de la comunidad? SI_____ NO_____ **(pasar a Ingresos)**

¿Qué le envían? (dinero, comida, etc.)______________________

¿Trabaja Ud., o alguien de la casa, en otras cosas que no son ganadería? SI_____(**sgte.)**
NO_____

¿En qué trabajan?___________________________________
¿Dónde?_____________________

Ingresos: ¿Cómo consiguen plata para comprar lo que no da en la comunidad? (Ej.: arroz, pilas, atún, etc.)

____

____

______

____

____

Materiales de la Vivienda

Techo:___________________________ Paredes: _________________________

Piso: ____________________________ Luz interior: ______________________

Coordenadas de la casa: X:____________________, Y:______________________

Código del GPS: ______________________

03. GANADO

Ganado	Alpaca		Llamas		Ovino	
	Machos	Hembra	Macho	Hembra	Macho	Hembra
Crias						
Tuis						
Adultos (hasta 4 años)						
Viejos						

¿Ha aumentado sus alpacas desde el año pasado: SI_____ NO_____

¿Por qué?

____

____

____

¿Ha aumentado sus llamas desde el año pasado?: SI_____ NO_____

¿Por qué?

____

____

____

¿Ha aumentado sus ovejas desde el año pasado?: SI_____ NO_____

¿Por qué?

____

____

____

¿Quién cuida el ganado? Papá_____ Mamá_____ Hijos _____ Pastor_____¿Cuánto pagan?______

¿Qué hacen si el ganado se enferma?

____

____

____

¿Cuántos tiene de cada uno de los siguientes animales?

	Perros	Gatos	Gallinas/pollos	Pavos	Cuyes	Otros (especif)
Cantidad						

Pastos

¿Cuántas áreas de pastoreo tiene?____________

¿En qué meses mueve/traslada el ganado de una área a otra de pastoreo?____________ ,

__________, ____________

¿Ha aumentado sus pastos desde el año pasado?: SI_____ NO_____

¿Por qué?

____

____

____

¿Tiene chacras/ tierras en agricultura? SI_____¿Qué cultiva?_______________
NO_____

04. REDES

Nombre a 5 o más compadres

1. ______________________________________
2. ______________________________________
3. ______________________________________
4. ______________________________________
5. ______________________________________

Nombre a 5 personas a las que les pediría dinero en caso de una emergencia

1. ______________________________________
2. ______________________________________
3. ______________________________________
4. ______________________________________
5. ______________________________________

Nombre a las 5 personas que pediría ayuda para hacer un trabajo (e.j. esquilar, matar animales)

1. ____
2. ____
3. ____
4. ____
5. ____

¿A quiénes (personas u organizaciones) pide información sobre la crianza del ganado y la venta de fibra, carne?

1. ____
2. ____
3. ____
4. ____
5. ____

05. MEDIDAS DE PREVENSIÓN CLIMÁTICA

¿Qué hace cuando hay helada? ¿Cómo cuida a los animales de la helada?

____

____

____

____

¿Qué hace cuando hay sequía? ¿Cómo cuida a los animales de la sequía?

____

____

____

¿Qué hace cuando hay inundación? ¿Cómo cuida a los animales de la inundación?

____

____

____

____

¿Hay comuneros o gente en la comunidad que conocen el clima? SI_____ NO_____

¿Sabe Ud. cuándo está cambiando el clima? ¿Sabe cómo va a ser el año (seco, lluvioso, frio, etc)? SI____ NO____

¿Cómo hacen para saber cómo va a ser el año?

____

____

____

¿Les han enseñado? SI_____ NO_____

¿Ven signos en nubes, pájaros, estrellas? SI_____ NO_____

¿Qué les preocupa más? (1 para el más importante, y 4 para el menos importante)

El cambio en el clima ____

La salud____

Conseguir dinero____

Educar a sus hijos____

MUCHAS GRACIAS!

Appendix 2: Guía de entrevista

01: # DE ENTREVISTA________, FECHA____________, HORA___________

DISTRITO:____________________, CARGO:________________________

02. TENENCIA

¿Cómo se obtienen pastos en la comunidad?

¿Hay reglas para conseguir pastos? ¿Y castigos para los que no las cumplen? ¿Se pueden perder los pastos que uno tiene?

¿Se puede tener tierras fuera de la comunidad?, ¿cómo?

¿De quién es el agua? (ríos, lagunas, puquios, deshielo, canales)

03. ECONOMÍA

¿Cuál es el trabajo más importante en la comunidad? (¿el que más realiza?, ¿el que no puede dejar de hacer cada año?) ¿Cómo se hace? ¿Quién ayuda? ¿Se contrata gente?

Incremento o cambios en las cantidades de ganado entre año.

Division del trabajo en la ganadería: género, edad, parentesco

¿Quién se encarga de qué?, y ¿cuándo?

Pastoreo

Sanidad

Las crías

La reproducción

Baño

El abigeato y los cazadores / predadores

Esquila

Venta

¿Cómo deciden movimientos del ganado?

¿Cómo seleccionan las áreas de pastoreo?

Los movimientos de ganado ¿se diferencian de acuerdo al tipo de ato? ¿Es un movimiento distinto si se trata solo de camélidos, de ovejas, o uno mixto?

¿Cómo deciden cuando es verano e invierno?, fecha calendárica o fenómeno climático

Pastos

Rotación de pastos: ¿cómo se realiza, quién decide el orden y tiempo en cada estancia?.

Conocimiento de la topografía y el clima en función de las necesidades especificas del ganado. ¿Hay mejores zonas para distinto tipo de ganado?, ¿para las crías?, ¿para las hembras preñadas?

Intercambio:

¿Cómo obtiene los productos que no produce?

¿Se desplaza a otros lugares con sus animales no necesariamente para que pasten?

¿Que vende de sus animales?

¿A quién le vende?, ¿con quién intercambia?, ¿siempre le vendió o cambio con las mismas personas?, ¿cambia de 'clientes'?, por qué?

¿Dónde vende sus productos?, ¿cómo determina los precios?

04. CAMBIO Y CONTINUIDAD (percepciones)

Preguntar sobre los cambios en el uso y control de los recursos respecto de los tiempos de la hacienda. ¿A qué tierras tenían acceso antes? ¿Quién las controla ahora?,

Tiempos de la hacienda, ¿qué y cómo han cambiado las cosas?

Aumento, disminución, mejor o peor calidad de los recursos (animales, pastos, agua)

Cambios en el clima

Duración de la época de lluvia (inicio y fin)

Tipo de lluvia (fuerte, ‘normal’, cambiada)

Cambios en la temperatura durante el día, la noche

Heladas, sequías, inundaciones

¿Qué se hace para responder a estos cambios? (comunidad y familias)

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